104

H.R. 655—THE HYDROGEN FUTURE ACT OF 1995

HEARING

BEFORE THE

COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

ONE HUNDRED FOURTH CONGRESS

FIRST SESSION

FEBRUARY 1, 1995

[No. 2]

Printed for the use of the Committee on Science

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H.R. 655—THE HYDROGEN FUTURE ACT OF 1995

WEDNESDAY, FEBRUARY 1, 1995

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE,
Washington, D.C.

The committee met, pursuant to call, at 9:03 a.m. in Room 2318, Rayburn House Office Building, Hon. Robert S. Walker [chairman of the committee] presiding.

The CHAIRMAN. The Science Committee will come to order for purposes of the hearing.

Let me apologize at the outset to our witnesses for the lack of large numbers of members in the room this morning. The minority party is caucusing, as is the majority party, and in the case of the majority party we have Al Gore appearing before the majority party, which I think most people thought that, even if there wasn't much information, it is going to be a good show, so we will have some people kind of wandering in later on, but for right now we don't have a lot of members in the room, but we will look forward to having them come in and be engaged in the questioning.

Let me begin by saying good morning and welcome to our witnesses and the members and the guests. Today's hearing is to receive testimony on H.R. 655, the Hydrogen Future Act of 1995. We have a distinguished panel of witnesses, and I am looking forward to the testimony and the questioning from our members.

A sustainable energy economy requires nondepletable resources which in turn requires a flexible, nonpolluting form of energy. Our Nation is looking for a virtually limitless supply of clean, efficient energy. The question is, where do we find it. Hydrogen is the energy source of the future. Because hydrogen is readily available from water and combusts leaving no noxious fumes but only water, we have a replacement fuel for our fossil-based economy.

Hydrogen has the potential of being used in as many ways and more as any available fossil fuel without the environmental costs. The major challenges to its use are finding an efficient means of converting primary energy sources to hydrogen while avoiding adverse environmental and other impacts and the lack of a compact, efficient means of storing hydrogen for mobile and stationary applications.

H H.R. 655, the Hydrogen Future Act, directs the Secretary of Energy to enhance the small Department of Energy hydrogen program. The Hydrogen Future Act will give added direction and funding stability by focusing Federal research on the basic scientific

fundamentals needed to provide the foundation for private sector investment and development.

The bill will not add to the deficit because it requires total authorization for the Department of Energy's Energy Supply Research and Development Account for fiscal years 1996, 1997, and 1998 be limited to no more than the total amount obligated for fiscal year 1995.

Briefly, I want to add that last year, with the cooperation of our ranking member, Mr. Brown, I introduced an almost identical bill. The bill is essentially the same as last year's which passed the House and was drafted to attract bipartisan support. So far, I have been somewhat disappointed that Mr. Brown has yet to be able to cosponsor the bill this year, but I am hopeful that the hearing will provide some additional information that will attract his cosponsorship as well as some of that from other members of the minority side, and I certainly extend to everyone on the committee an invitation to work with me on supporting this legislation through the House. Mr. Brown, in particular, has a long history of support of hydrogen R&D which is well known, and we certainly want to make this into a cooperative, bipartisan effort wherever we can.

Before I introduce our witnesses I would like to recognize Mr. Brown for any comments he would like to make.

Mr. BROWN. Thank you very much, Mr. Chairman, and I do appreciate your kind words with regard to my previous support and for hydrogen research and our cooperation together in this area.

I share his enthusiasm for the role that hydrogen may play in solving our Nation's long-term energy problems. Next week the committee will mark up the bill. While I did cosponsor the program in the past, I did not cosponsor H.R. 655, and let me just briefly explain why. It has nothing to do with the hydrogen research aspects of the bill. I would thoroughly support those. I am a notorious exponent of big spending on research, and this falls well within that category.

However, the problem I have and which I had last year on some legislation is that there is an effort in this bill to put a cap on a major part of the Department of Energy spending. Now I am not necessarily opposed to doing that, except I would like to know what the impact is, and I have not been able to find that out at the present time.

I hope that as I get further information with regard to the impact of a cap such as this, which is based upon fiscal year 1995 outlays, to be able to determine whether or not the effect is such that it would cause me to be able to cosponsor this bill. I hope the chairman will keep his invitation open, because I would very much like to cosponsor the bill, and we will just see how that plays out.

I have no further remarks, Mr. Chairman, except I ask unanimous consent to revise and extend, and if anyone else on my side would like to have some time, why—

The CHAIRMAN. Yes, without objection on the unanimous consent.

I would welcome opening statements from any other member that feels that they would like to participate in opening statements this morning.

The CHAIRMAN. If there are no further opening statements, we will then proceed with our distinguished panel of witnesses. From

the Department of Energy we have with us Christine A. Ervin, assistant secretary for energy efficiency and renewable energy. Our witnesses from the science community and industry include Dr. Alan Lloyd, chief scientist for the South Coast Air Quality Management District in Diamond Bar, California; Mr. Ed Trlica, president of Energy Partners from West Palm Beach, Florida; and Dr. Robert H. Williams, senior research scientist at the Center for Energy and Environmental Studies in Princeton, New Jersey.

It is my understanding that Mr. Trlica is a constituent of Mr. Foley.

Do you wish to say anything with regard to Mr. Trlica's presence with us this morning, Mr. Foley?

Mr. FOLEY. Thank you, Mr. Chairman, and obviously thank you for Mr. Trlica making the journey to Washington.

We are indeed proud of the company, Energy Partners, its location in Palm Beach County, and Mr. Perry's commitment towards the development of alternative fuel sources, his personal commitment over $25-$30 million out of personal funds to make this dream a reality, and I applaud his coming to Washington to be with us today.

The CHAIRMAN. Thank you, Mr. Foley.

I would remind our witnesses that we encourage you in the strongest possible terms to limit your oral statements to five to seven minutes, and we will include all of the written material that you have submitted for the record so that you are assured that we have the full range of your opinions on this, but it does give us more time to get in questions if you can limit your opening statements.

We thank you for that, and we will begin with Secretary Ervin.

STATEMENTS OF HON. CHRISTINE A. ERVIN, ASSISTANT SECRETARY, ENERGY EFFICIENCY AND RENEWABLE ENERGY, U.S. DEPARTMENT OF ENERGY, WASHINGTON, D.C.; ALAN LLOYD, CHIEF SCIENTIST, SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT, DIAMOND BAR, CALIFORNIA; EDWARD TRLICA, PRESIDENT, ENERGY PARTNERS, WEST PALM BEACH, FLORIDA; AND ROBERT H. WILLIAMS, SENIOR RESEARCH SCIENTIST, CENTER FOR ENERGY AND ENVIRONMENTAL STUDIES, PRINCETON UNIVERSITY, PRINCETON, NEW JERSEY

Ms. ERVIN. Thank you, Mr. Chairman and members of the committee. I am very pleased to be here this morning to talk about the Department of Energy programs for hydrogen and also to talk specifically about this bill, the Hydrogen Future Act of 1995.

I would like to introduce the deputy assistant secretary for utilities, Karl Rabago, right behind me, and Dr. Marvin Gunn, who formerly oversaw the energy management programs in my office and is now directing my Management of Resources Office for me. I know he has testified before this committee in the past.

I would like to start by expressing my strong appreciation to Chairman Walker and to members of this committee for your leadership in recognizing the potential offered by hydrogen. The Department recognizes this potential as well and concurs in the vision of the Hydrogen Technical Advisory Panel that hydrogen will join

electricity in the 21st century as a primary energy carrier in the Nation's sustainable energy future.

The mission then of the DOE-sponsored hydrogen research is to encourage and support the development of safe, practical, and economically competitive hydrogen technologies and systems to meet transitional and large-scale energy needs. Since its inception 15 years ago, the hydrogen program has evolved into, I think, a truly innovative strategic effort that draws heavily from industry, from the Hydrogen Technical Advisory Panel, and from other experts.

Now let me turn to general comments on the bill. The Department supports the major thrust of the findings the purposes and programmatic goals of this bill. We are concerned, however, that the detailed provisions of the bill tend to be overly prescriptive and may inadvertently restrict opportunities for the Hydrogen Technical Advisory Panel and industry to shape and help direct this evolving research and development program. We would be happy to work with you, with the members of this committee, on the bill to maintain flexibility in meeting the commonly shared goals of Congress, the Department of Energy, and industry as a whole.

Now let me address the specific provisions of the bill. The Department recognizes the importance of developing and demonstrating technologies for hydrogen production, storage, and use as described in sections 5(b), 5(c), 5(d), and 5(e) of this bill. However, the Department strongly believes that the timing and the selection of technologies for demonstration projects should be based to a great extent upon input from industry and the Hydrogen Technical Advisory Panel rather than as specifically prescribed in the bill.

The requirement contained in section 5(f) for issuance of a solicitation within 180 days after enactment of the bill may also be overly restrictive. The Department believes that the best course of action is to issue solicitations for new research and development activities in accordance with its hydrogen program plan and implementation plan which does lay out a schedule for solicitations on particular technologies.

The Department is in general agreement with the provisions of sections 5(g), 5(h), sections 6 and 7 regarding cost sharing, duplication of efforts, highly innovative technologies, and technology transfer. Regarding section 8 of the bill, the Department produces summary reports on the research and development activities as well as activities of the advisory panel and of course would be happy to make any and all of those reports available to Congress.

The Department also agrees with the coordination and cooperation provisions required under section 9 of the bill.

Now section 10 repeals sections 104 and 105 of the Spark Matsunaga Hydrogen Research Development Demonstration Act. These sections did provide priority to hydrogen production technologies based upon renewable energy sources, and the Department believes that these production technologies should remain a priority in the program.

Section 11(a) is in agreement with our planning activities at the Department. However, section 11(b) defines the appropriations will be distributed, and that may be overrestrictive, could limit the effectiveness of the Hydrogen Research and Development Program.

The Department as well as the administration does strongly oppose section 11(c) that would cap obligations for energy supply, research, and development activities at the 1995 level through 1998. We believe this would impose an inflexible cap that would limit the Department's ability to carry out many of its most important missions and places an artificial cap unrelated to the Nation's needs on one-fifth of the Department's budget and programs.

So that concludes my specific comments. Once again, thank you very much for providing me with the opportunity to comment on this bill, and I will of course be happy to answer any questions that you have.

[The prepared statement of Ms. Ervin follows:]

Testimony

of

Christine A. Ervin
Assistant Secretary
Energy Efficiency and Renewable Energy
U.S. Department of Energy

Before

Committee on Science
U.S. House of Representatives

H.R. 655
The Hydrogen Future Act of 1995

February 1, 1995

Mr. Chairman and Members of the Committee:

INTRODUCTION

I am pleased to appear before the Committee to review the Department of Energy programs for hydrogen and to discuss H.R. 655 the " Hydrogen Future Act of 1995." The Department recognizes the potential offered by hydrogen, and has embraced a vision proposed by the Hydrogen Technical Advisory Panel, that hydrogen will join with electricity in the 21st century as a primary energy carrier in the Nation's energy future. Both energy carriers will ultimately be derived from renewable resources and be delivered via pathways linking production, storage, and distribution steps to end-users for a variety of applications. However, fossil fuels will provide a long-term transitional resource. Hydrogen will ultimately offer a non-polluting, potentially efficient and cost-effective energy system that could be derived entirely from domestic energy sources. Realization of this bold vision could enable this Nation to gain a significant share of the world's future hydrogen technologies market. Once hydrogen energy systems are cost-effective, many jobs will be created in newly emerging hydrogen industries. The mission of the DOE-sponsored hydrogen research is to encourage and support the development of safe, practical and economically competitive hydrogen technologies and systems to meet transitional and large-scale energy needs.

This testimony will first address the background and core research and development elements of the Department of Energy's Hydrogen Program. I would also like to comment on collaborative efforts, partnerships with industry and emerging markets. Finally, I have provided both general and specific comments on H.R. 655 for your consideration.

BACKGROUND

I am pleased to report that the Department has made considerable progress in implementing its hydrogen research and development program consistent with the Spark Matsunaga Hydrogen Research, Development and Demonstration Act of 1990 and the Energy Policy Act of 1992. The Office of Energy Efficiency and Renewable Energy is responsible for managing the hydrogen program and for coordinating hydrogen-related activities throughout the Department. The Offices of Energy Management, Transportation Technologies, Industrial Technologies, and Energy Research are conducting hydrogen-related research, development, and demonstration programs for clean affordable technologies that will decrease the costs of producing, storing, and using hydrogen and hydrogen-rich gas streams; and will develop the reliable and efficient infrastructure needed to expand the use of hydrogen in energy markets. The hydrogen program is divided into three major elements: technology development (core research and development, "R&D"), demonstration activities, and systems analysis. The Department funds a balanced core of research and development projects in the areas of production, storage, distribution and utilization to achieve the goals set out in its five-year Hydrogen Program Plan. The demonstration element consists of two sub-elements: identification of promising, cost-shared demonstration projects (part of industry outreach) and demonstration projects. In addition, the Office of Fossil Energy supports research and development activities linked to the hydrogen program, particularly for near-term applications. The current hydrogen plan contains the recommendations of the Hydrogen Technical Advisory Panel (HTAP) and other key stakeholders for implementing and conducting the program.

CORE R&D ELEMENTS

The Department has concentrated its core R&D element upon the development of high-payoff technologies with near-, mid- and long-term development cycles. A typical long-term project in this element is the photobiological production of hydrogen. This project includes the development of genetically engineered bacteria and algal systems to use photon energy to split water into hydrogen and oxygen or to convert carbon monoxide and water into hydrogen and carbon dioxide. The technical challenges are great; however, if this approach is successful, it would provide an environmentally benign renewable production method for hydrogen. Core R&D funding provides researchers with the opportunity to overcome many of the challenging technical hurdles.

Other core R&D efforts address lower-risk, near-term technology development. Two new projects initiated in FY1995 demonstrate this focus. The first is a cost-shared, five year technology development program consisting of an advanced steam-methane reformer that will operate at a reduced temperature and thereby offer major environmental and cost benefits. The second is a cost-shared, three year development effort with a small business to produce a solar induced production and electrolysis system for the production of hydrogen as a fuel for remote areas.

Overall, the Department has taken an aggressive and proactive posture to implement its hydrogen program. The Department has benefitted from significant stakeholder involvement, especially recommendations provided to the DOE at its public Hydrogen Technical Advisory Panel meetings, in the development of the plan. The Department appreciates the strong support which the Committee, and

particularly Chairman Walker, have provided.

COLLABORATION

DOE has been encouraging collaborations with other Federal agencies, State and local governments, and industry as well as promoting cost-shared and industry-driven projects. Within the Department, there are collaborations (meetings, proposal review, peer review, and discussions of monthly reports) between the hydrogen and hydrogen related development programs within the Offices of Transportation, Industry, Buildings, and Utility Technologies. These include: the fuel cell program for transportation under the "Partnership for a New Generation of Vehicles" - the industry/government partnership to develop highly efficient, safe vehicles for the next century; advanced hydrogen fueled internal combustion engines for hybrid vehicle applications; fuel cells for building cogeneration; biomass gasification for electrical power generation and alternative fuels; and purification of hydrogen from process gases.

In addition to the Department's internal collaborative efforts, for each research category (e.g. production), an industry "Working Group" has been organized to provide regular guidance and feedback to the DOE on industrial efforts to develop technologies for hydrogen energy systems. Composed of industry, researchers from participating universities, and national laboratories, the group meets regularly each year and forms the cornerstone of technology interchange in the hydrogen program. The industry participants benefit by having direct access to all program researchers.

PARTNERSHIP WITH INDUSTRY

The Department believes that industry support and participation are essential for planning and carrying out demonstrations of key technologies and processes, and will lead to early commercial applications in niche markets. The Department has assumed the Federal leadership role in forming industry partnerships for the long-term development and demonstration of advanced technologies for the integration of hydrogen energy systems into the Nation's energy infrastructure. These partnerships are being nurtured and sustained through an industry outreach effort to increase participation in the development of the hydrogen infrastructure. Moreover, other sectors such as the natural gas utilities and the electric utilities must be encouraged to consider the merits and viability of hydrogen options. One way to foster utility interest is for DOE to present a credible scenario of a transition from natural gas based hydrogen production for niche energy markets to biomass based hydrogen production in the mid-term and finally to solar hydrogen and/or biologically catalyzed hydrogen production in the long term. Simultaneously, DOE must also provide a vision of a plausible evolution of an infrastructure that will safely and reliably distribute hydrogen to end-users.

MARKETS

The demand for "clean" end-use applications is growing. Proactive states, such as California, are considering hydrogen energy systems as an approach to achieving zero emission end-use technologies, such as zero emission vehicles and urban power generation equipment. The Department is working in partnership with the South Coast Air Quality Management District and the California Air Resources Board to foster, deploy, and demonstrate hydrogen technologies in California as

they become available. The Department is pursuing the development of near-zero emission vehicles (e.g., powered by fuel cell, internal combustion engines, and hybrids) under the Administration's PNGV effort, stationary power generation (gas turbines and fuel cells) for utility and building sector applications, and local production and distribution (small natural gas reformers and storage subsystems) that will meet these requirements and create the market demand for a hydrogen energy infrastructure.

One example to accelerate hydrogen from a mere possibility to a real energy option is getting fuel cells into the market as quickly as possible. This is needed both to gain hands-on experience with fuel cells and to ensure that U.S. companies achieve promises of scale needed to capture the global market. Fuel cells are most likely to break into the market as distributed, stationary power sources, particularly for buildings because of the opportunities to provide both electricity and hot water at competitive costs and with virtually no pollution. Coupling the deployment of fuel cells with continued improvements in energy-efficient lighting, heating, cooling, window and control technologies allows fuel cells to overcome first-cost hurdles that challenge all new technologies.

GENERAL COMMENTS ON H.R. 655

Now let me turn to general comments on the bill. The Department supports the major thrust of the Findings that hydrogen is a promising fuel, as well as the purposes and programmatic goals of the bill. However, the Department believes that the bill tends to be overly prescriptive and encourages the Congress to amend the bill so as to maintain maximum flexibility in meeting the commonly shared goals of Congress, DOE, and the industry as a whole. For example, the

Department already consults with the Hydrogen Technical Advisory Panel in establishing program priorities and implementation plans. Some of the prescriptive details in the current bill would limit the ability of the panel, industry and other stakeholders to shape program design and implementation. DOE would be happy to work with the Committee on this bill.

SPECIFIC COMMENTS

Turning to specific comments, in considering Section 5 on Research, Development, and Demonstration, the Department has recognized the importance of developing and demonstrating technologies for producing hydrogen from renewable energy sources and storing hydrogen for mobile and stationary applications. The Department is currently supporting core R&D projects in nearly all of the areas specified in Sections 5(b) Production, and 5(c) Storage. The Department strongly believes that the selection of demonstration projects should be based upon recommendations and willingness to cost-share by industry.

The Department currently supports focused R&D efforts to develop and demonstrate hydrogen-based transportation vehicles (Section 5(d)). The DOE is managing a number of research and development activities for vehicles that will meet the low and zero emission levels mandated by several states. These include: (1) internal combustion engines fueled with blends of natural gas and hydrogen, as well as 100% hydrogen, that can be used as a sole power source or combined with a secondary power source in an electric or hybrid vehicle; and (2) fuel cell vehicles. In addition, the Department is already planning demonstrations of these technologies and has been meeting with industry interested in leading demonstration efforts.

Section 5(e) would establish research and development for hydrogen end-use applications including electrical generation, heating and cooling, and aircraft fuel. The DOE Office of Fossil Fuels is currently managing R&D activities on technologies to separate hydrogen from impurities resulting from the coal gasification process, for use in hydrogen fuel-cells that generate electricity. NASA is focusing R&D efforts on hydrogen storage and distribution technologies for the use of hydrogen as a fuel in its space shuttle and proposed National Aerospace Plane programs. Any proposed activities in hydrogen end-use applications will be fully coordinated with the appropriate offices and agencies.

Section 5(f) would require the Department to issue a solicitation within 180 days of the enactment of this Act. The Department believes that the best course of action is to issue solicitations for new R&D activities in accordance with its Hydrogen Program Plan and Implementation Plan.

Section 5(g) would require the cost-sharing of appropriate R&D efforts. The Department strongly supports cost-sharing with the private sector and agrees with the provisions outlined in this section. The Department also agrees with the provisions outlined in Section 5(h) addressing duplications of efforts.

Section 6 would require the funding of highly innovative technologies. The Department agrees with the provisions outlined in this section and will implement new R&D projects in accordance with the five-year Program Plan and Implementation Plan. Since radical improvements to the economics of hydrogen production and storage are key to commercial success for hydrogen systems, these innovative approaches may have to be funded at more than the minimum 5% of the budget.

Section 7 would require the Department to carry out technology transfer of generic R&D information. The Department agrees with the provisions outlined in this section and has undertaken an aggressive outreach effort to transfer information and technology to industry through interactive meetings, workshops, and cooperative projects.

Section 8 would require the Department to report to the Congress on the status and progress of the hydrogen program. The Department already produces summary reports on the status of the R&D activities and is pleased to make them available to the Congress. Reports on the activities of the Hydrogen Technical Advisory Panel are also available on a regular basis.

Section 9, Coordination and Cooperation, would require the Department to coordinate all hydrogen activities with other Federal agencies. The Department agrees with the provisions outlined in this section and has already implemented a comprehensive coordination effort in cooperation with the Hydrogen Technical Advisory Panel.

Section 10 would repeal sections 104 and 105 of the Spark Matsunaga Hydrogen Research, Development, and Demonstration Act. These sections provide priority to hydrogen production technologies based upon renewable energy sources. The Department believes that these production technologies should remain a priority in the program.

Section 11(a) Authorization of Appropriations is in general agreement with the planning activities of the Department; however, section 11(b) defining how the

appropriations will be distributed is very restrictive and could limit the effectiveness of the hydrogen research and development program and its ability to respond to industry interests and priorities.

The Administration strongly opposes section 11(c) which would cap obligations for energy supply research and development activities at the 1995 level through 1998. This inflexible limit will impede Department's ability to carry out its missions in a prudent and effective manner. This places an artificial limit, unrelated to the Nation's needs, on the management of one-fifth of the Department's budget and programs. Such a restriction would be objectionable in any legislation but is wholly inappropriate in technology specific legislation such as this.

CONCLUSION

The Department has successfully met the challenge of developing and implementing a hydrogen plan delivering near-, mid-, and long-term benefits from proven hydrogen energy technologies. Since its inception more than fifteen years ago, the Department's Hydrogen Program has evolved into an innovative, targeted, and industry-driven effort. Provisions of the Matsunaga Act (P.L. 101-566) and the Energy Policy Act (P.L. 102-486) have contributed strongly to this success, including creation of the Hydrogen Technical Advisory Panel, and development and implementation of the Hydrogen Multi-year Program Plan. Many of the provisions of H.R. 655 underscore the potential of hydrogen to meet energy supply needs, the need for strong industry partnerships, and continued support for this research. The Department's hydrogen program is strategically focused and is an efficient

means of producing the necessary technology to ensure that hydrogen will be a significant contributor to the Nation's sustainable energy future.

Thank you for providing me with the opportunity to testify before the committee. I would be happy to respond to any questions the Committee may have.

The CHAIRMAN. Thank you very much.

Dr. Lloyd.

Mr. LLOYD. Good morning, Mr. Chairman and members of the committee.

My name is Alan Lloyd, chief scientist with the South Coast Air Quality Management District in Southern California. I am also a member of the Hydrogen Technical Advisory Panel established under the Matsunaga Act. I am very pleased indeed to be here to be here today to participate in these hearings.

First, I would like to compliment the author of H.R. 655 for proposing additional actions to accelerate the hydrogen agenda. This will help ensure that the potential environmental and energy diversification benefits of hydrogen are realized. Additionally, I want to recognize the long-term support of Congressman Brown for hydrogen because of its environmental and energy benefits. I also want to compliment the Department of Energy for its efforts to develop a comprehensive plan for hydrogen. This plan is an important first step, but we believe that an expedited and expanded effort is ultimately needed. My remarks are therefore meant to facilitate and accelerate the Federal role in commercialization of hydrogen technologies.

The principal reason that we strongly support hydrogen is our pressing need for zero and near zero emission technologies to restore healthful air in the Los Angeles Basin. Hydrogen will provide tremendous environmental benefits while diversifying energy use in our transportation sector which is effectively 100 percent dependent on petroleum fuels.

There is another reason, perhaps less obvious, why we support acceleration of hydrogen technologies. We believe it is a strategic investment in America's continued status as an economic and technology powerhouse. The market for clean technologies in California alone has already reached about $20 billion per year. Worldwide, by the year 2000 it will exceed $300 billion per year.

Major metropolitan areas all over the world and megacities are in need of fuel cells and other hydrogen-related technologies to mitigate the serious pollution problems. Simply put, America must be prepared to capitalize on this vital and burgeoning world market for clean technologies or we will be left behind.

Regarding the bill itself, I am supportive of its overall thrust. However, there are several areas that I recommend changes. I recommend that it be recast to put more emphasis on leveraging the existing programs rather than adding to programs already under way. For example, I believe that the bill could significantly add to the national agenda by focusing on a systems approach which would pull together the various components of hydrogen technology into an actual demonstration led by public-private partnership or partnerships. I believe it is only in this way that we will be able to accelerate the utilization of hydrogen in the energy mix. In this regard, the Department of Energy should give high priority to the preparation of a demonstration plan that incorporates the various technologies being supported by the Government and private industry.

The Department of Energy has an extensive though modestly funded hydrogen R&D program under way, and I am supportive of

providing additional funds for R&D work in several essential areas such as storage technology, low-cost generation processes, but this work should be fully integrated into an overall systems approach where the economics of the whole system can be analyzed and tested.

R&D work also on hydrogen use in jet engines should also be supported. We strongly support the use of renewable energies—renewables for hydrogen generation. From an environmental viewpoint, we see substantial local, regional, and global benefits. The bill needs to clarify that this would remain a key thrust in DOE's hydrogen agenda.

As I have suggested in my written comments, one of the important ways to expedite hydrogen and to build an infrastructure, which is critical to the success of any fuel program, is to deploy a series of geographically strategic demonstration corridors. This would couple the various hydrogen subsystems to an overall systems demonstration.

For example, there is a program in Southern California to link approximately 10 hydrogen-related projects in a so-called desert-to-the-sea demonstration. This proposal involves Federal, State, regional, and local governments, cities, teamed with the private sector, academia, and interest groups. I think this is a unique thing. Other opportunities clearly exist in the Midwest for similar demonstrations and also in the Southeast such as Florida and Georgia around the Olympics.

It is also important to recognize that Government bureaucracy can actually be reduced when dealing with zero or near zero emission technologies and fuels. For example, applications or facilities utilizing hydrogen may not require air pollution permits for operation. Our own district already has a rule on the book that exempts fuel cells from our permitting process. This is a significant economic incentive to develop and deploy hydrogen technologies.

With hydrogen-related efforts by the Federal Government and other entities clearly on the rise today, I have two suggestions for the improved operation and administration of such emerging programs.

One, a Hydrogen Technology and Utilization Office should be created within the Department of Energy. This office would improve the coordination of hydrogen programs within the Federal Government and make them more cost effective.

Two, in order to ensure full cooperation with the private sector and also to stream the actual implementation of programs, consideration should be given to the creation of an external office such as the hydrogen industry consortium which has been suggested by the Hydrogen Technical Advisory Panel set up under the Matsunaga Act. This office could be strongly linked with the HTAP and utilized to raise R&D funding in addition to providing oversight to the programs. It should be noted that an existing entity such as the National Hydrogen Association could also be considered to fill that role.

To summarize, I support the thrust of H.R. 655 to put additional resources into hydrogen technology and of its desire to get more private sector involvement, but I believe that the bill can be strengthened by incorporating the suggestions detailed above.

Thank you very much, Mr. Chairman and members of the committee, for allowing me to address you today.

[The prepared statement of Mr. Lloyd follows:]

HYDROGEN'S FUTURE ROLE IN THE NATIONAL ENERGY MIX AND ASSOCIATED RESEARCH, DEVELOPMENT AND DEMONSTRATION PROGRAMS TO EXPEDITE ITS COMMERCIALIZATION

Presented Before the United States House of Representatives

Committee on Science

February 1, 1995

Alan C. Lloyd, Ph.D.
Chief Scientist
South Coast Air Quality Management District
Diamond Bar, California

Good morning Mr. Chairman and Members of the Committee. My name is Alan Lloyd, Chief Scientist of the South Coast Air Quality Management District in Southern California. I am also a member of the Hydrogen Technical Advisory Panel (HTAP) established by the Matsunaga Act. I am very pleased to be here to address: a) my overall reaction to the issues you have raised in your letter of January 25, 1995; b) the future role hydrogen can play in the national energy mix, and c) specific research, development and demonstration programs that can be undertaken to expedite its commercialization. My comments are broken out accordingly.

OVERALL COMMENTS

I am pleased to see the Chairman and this Committee address the increased support of hydrogen commensurate with its potential to address energy and environmental issues, as well as providing opportunities for developing technologies with global markets. In the last few years I have witnessed an increased interest in the use of hydrogen to address energy security and environmental issues. There has also been a substantial improvement in practical application, particularly for fuel cells. No doubt this higher visibility for hydrogen is due to the Matsunaga Act and the ongoing programs at the Department of Energy (DOE) and other federal agencies. Having worked with the staff at the DOE, I want to congratulate them for their efforts to develop a comprehensive hydrogen program in line with the Matsunaga Act. I would also like to compliment the Chairman for ensuring hydrogen's rightful place in the national energy agenda, particularly because of its growing importance as we go into the next century. My comments come from a desire to strengthen the proposal before you so that meaningful programs are enacted that advance the cause of hydrogen through a coordinated public/private application program. Such a program will result in a much larger payoff, rather than a mere continuation of more fragmented R&D efforts.

In this section, I will provide some overall comments, followed by some specific suggestions.

- While I recognize that the proposal acknowledges the need for continuing R&D to increase the cost effectiveness of the various technologies, it should contain a greater emphasis on the application side. In that light, it should include a provision

directing the preparation of a report, to be prepared within 90 days rather than the 180 days mentioned in your letter , which will link all the ongoing programs in a meaningful and cost-effective way. This report should indicate where elements of this proposal would yield comprehensive demonstrations rather than piecemeal approaches of uneven quality and duration. I will give one example of such a demonstration later.

- It is not clear from the contents of your letter requesting my comments that there will be continued encouragement of renewable energy. I feel strongly that renewable energy should continue to be one of the key ingredients of hydrogen generation technology and should be included in major comprehensive demonstration programs.

- The proposed language should also require a closer link between the various aspects of hydrogen R&D and the application of hydrogen in fuel cells. Fuel cell technology has seen substantial improvements in the last few years, and the most effective way to utilize hydrogen is through the high efficiencies available in fuel cells. The fuel cell has an advantage in that it can be coupled with a variety of hydrogen carriers, all of which are relevant to the overall umbrella of hydrogen--its generation, storage and utilization.

- The timeframe for initiation and completion of many of the actions identified in the proposal should be cut in half. The bill should also require a short, focused study to explore ways to facilitate the utilization of the money and cut a lot of the government red tape which unnecessarily impedes the progress of these projects. Giving some of the dollars to appropriate industry entities or consortia may be a vehicle worth exploring. At least two examples come to mind, the National Hydrogen Association or a new entity called the Hydrogen Industrial Consortium (HIC) suggested by the Hydrogen Technical Advisory Panel. General oversight could be provided by the Hydrogen Technical Advisory Panel established by the Matsunaga Act. This would also address one of my other concerns; namely, the proposal should be more industry-driven. Based on my own experience, this should be a public/private partnership driven by industry demands and interest, which will assure the successful implementation and commercialization of the relevant technologies.

Thus, while overall this proposal should be applauded for continuing to recognize the key role for hydrogen, it could be substantially strengthened by focusing on the need for a broader "systems approach." This approach should be based on actual demonstrations, incorporating the relevant R&D results from the many ongoing research programs that form the overall system.

HYDROGEN AND THE NATIONAL ENERGY MIX

It is well recognized that hydrogen has distinctive benefits. These benefits, which may be classified as the four Es, should establish hydrogen as an important candidate in tomorrow's national and international energy mix:

- Environmental
- Energy Efficiency
- Energy Independence
- Export Markets: Worldwide

As the Chief Scientist of an air quality agency, my primary involvement with hydrogen has been to explore its technical benefits and potential to significantly reduce air pollution. I have attached to this testimony a paper I plan to present at an upcoming international conference on the role of hydrogen in meeting Southern California's air quality goals. The paper outlines the air quality background of the region, the significant emissions reductions needed, the type of technologies with which we are involved, and specific hydrogen projects we are pursuing in the region. In my remarks, I will highlight some of the main arguments related to air quality for supporting hydrogen.

Environmental

Few fuels can parallel the enormous benefits that hydrogen brings to the environmental field. Hydrogen represents a quantum leap forward in reducing environmental impacts from both stationary and transportation sources of pollution.

Regarding air quality, hydrogen has the potential to eliminate a wide range of pollutants from both motor vehicles and stationary smokestacks. These pollutants include: a) criteria pollutants, such as reactive organic gases (ROG), carbon monoxide (CO), fine

particulate matter (PM10) and sulfur oxides (SOx); (b) toxic pollutants such as benzene, polycyclic aromatic hydrocarbons, and formaldehyde; and (c) global warming gases such as methane and carbon dioxide.

Tailpipe emission reductions alone are not sufficient for the South Coast Air Basin to meet its air quality objectives by year 2010. Reductions of mobile source evaporative and fueling emissions are needed as well. Hydrogen has the potential to eliminate both types of emissions.

Regarding other environmental benefits, hydrogen has a minimal impact on land, surface water and the ocean. Given its capacity to rapidly dissipate into the atmosphere, hydrogen leaks or spills have either no or negligible impact on underground water, rivers, lakes, ocean, and other segments of the ecosystem.

Because of the positive environmental benefits of hydrogen, its application can lead to a significant reduction in regulations imposed on the private sector. For example, the South Coast Air Quality Management District does not require permits for zero, or essentially zero, emissions technology such as fuel cells. These are direct incentives for the private sector to pursue clean technologies.

Energy Efficiency

Widespread use of hydrogen is expected to evolve in at least two ways. One path involves the development or modification of internal combustion engines to use pure hydrogen. (Hydrogen is sometimes burned in combination with fuel containing hydrocarbons such as natural gas-- known as "Hythane"™ because it consists of hydrogen and methane--to improve combustion or lower costs.) According to scientists at the Lawrence Livermore Laboratory, in a hybrid mode where hydrogen is burned in an internal combustion engine at a steady-state, and where peak power is provided by an energy storage device--such as an ultracapacitor, battery or a flywheel--efficiencies of over 45% can be achieved.

The second path, involving electrochemical conversion of hydrogen for power through fuel cells, offers significantly higher energy conversion efficiency with zero or near-zero emissions. Efficiencies of 40% or more are expected in a hydrogen fuel cell. These efficiencies are 2 to 2 1/2 times more efficient than conventional spark-ignited gasoline

engines. We prefer the use of hydrogen in this second application--the fuel cell--because of these emissions and efficiency benefits. The direct cost savings alone of such increased efficiencies would ensure rapid payback of any investment the federal government may make in encouraging the widespread use of hydrogen. Major progress has been made over the past few years to develop and demonstrate fuel cell applications. Examples include the DOE/DOT/SCAQMD fuel cell bus, the numerous fuel cells provided worldwide by ONSI/IFC, and Ballard's impressive fuel cell buses, which use compressed hydrogen as a fuel.

Energy Independence

Since the final product of hydrogen use is water-vapor, hydrogen fuel has the potential to be endlessly sustainable if produced from water or biomass using renewable energy. Unlike many conventional fuels, in the long-run this could enable the United States to be truly energy independent.

In the near future, renewable-based hydrogen would encourage fuel supply diversity and make possible new choices and competition in energy markets. Substantial inter-regional energy trade could occur with a diversity of energy carriers and suppliers. Energy importers would be able to choose from among more producers and fuel types than they do today, and thus would be less vulnerable to monopoly price manipulation or unexpected disruptions of supplies. Such competition would make wide swings in energy prices less likely (Burham, L, 1993). Moreover, in contrast to current oil-import projections, the U.S. could become less reliant on Middle Eastern oil which, in turn, could substantially help improve the staggering trade deficits currently confronting the domestic economy.

Because hydrogen can also be made from a variety of fuels--such as the more conventional petroleum-based fuels, as well as from methanol, natural gas, and the renewable fuels mentioned above--the dependence on any one particular source is minimized. Therefore, energy security and independence is maximized. We support the investigation of hydrogen generation from all these sources.

Export Markets: World-Wide

The market for hydrogen and hydrogen-based technologies, such as hydrogen generation plants, storage technologies, and fuel cells, goes well beyond America. Many cities throughout the world, particularly those in Eastern European and Third World countries, have extreme pollution problems. Awareness and consciousness of the need for cleaner air will stimulate a major demand in the international economy for American-made clean air technologies. This is already happening in Taiwan and Mexico City and other mega-cities worldwide.

The worldwide market for environmental goods is expected to top the $300 billion mark by year 2000. However, there is no guarantee that American technology will prevail. Japan, Germany and Canada have initiated important programs in hydrogen technologies. These include the WE-NET and the Euro-Quebec projects, and the hydrogen programs initiated by Mazda, BMW, Mercedez-Benz and Ballard. To compete, American companies need both fiscal and regulatory incentives from the federal government to develop hydrogen-based technologies.

In 1993, President Clinton said there were three million people employed in export-oriented jobs. This number will expand considerably if American companies develop and refine zero-emission technologies, such as hydrogen and fuel cell products for domestic and overseas markets. The federal government can and should be an active partner.

RESEARCH, DEVELOPMENT AND DEMONSTRATION PROJECTS

I applaud the Committee for its continuing support for hydrogen research, development and demonstration (R,D &D) projects with the caveats mentioned above, namely that there is no duplication of effort from on-going work at the Department of Energy, and that there is more support for a system-wide approach as outlined below. In addition, I would encourage the Committee to focus on those R,D &D projects that will enable hydrogen to be used widely in transportation and stationary power applications. Given all its desirable features, I hope that hydrogen quantities, now measured in cubic feet, would in the future be measured in quads--just like natural gas and petroleum are today. Your decisions could lay the foundation for such a future.

Systems Approach Recommended

Using substantial industry participation, I would encourage the Committee to adopt a systems approach to demonstrate, in an integral fashion, various components of the hydrogen infrastructure. It is important to understand the interrelationship of the various components and how these fit in to the commercial end product.

Currently, plans call for a piece-meal approach, and while technical progress is still required in areas such as hydrogen storage, they may be better demonstrated as part of an overall system rather than stand-alone entities. Such system demonstrations could bring together fundamental segments of a future hydrogen infrastructure. Included in these demonstrations would be a requirement to look at the economic aspects of the overall system as well as its components. Given our experience with trying to commercialize alternative fuels and new technologies, this system-wide approach, in which the fueling infrastructure development is a key aspect, is fundamental to accelerating hydrogen on the local, regional and national agenda.

Examples of the systems approach that I would envision would be a recommendation for "hydrogen corridors" to be initiated in various regions of the USA. For example, in a corridor for the midwest, hydrogen production from biomass and wind energy can be showcased. In Florida much of the on-going work in energy generation and storage could be focused on a regional demonstration, whereas in Atlanta, hydrogen-hybrid internal combustion engines and hydrogen fuel cell buses could be demonstrated in time for the Summer Olympics in 1996.

Another proposed system demonstration would be the Southern California Hydrogen Corridor, with which I am very familiar. Because of the number of hydrogen-related projects in California, we and others are exploring the possibility of a hydrogen corridor, that stretches from Santa Monica and Torrance in the west to Palm Desert in the east. The corridor will attempt to comprehensively demonstrate hydrogen as a viable transportation fuel. The corridor will link half a dozen existing hydrogen demonstration projects and accommodate additional demonstrations:

- Chrysler/Allied Signal/DOE-sponsored direct hydrogen-fueled PEM transportation program at Torrance (existing)
- Xerox-Clean Air Now Project near LAX (existing)
- University of California, Riverside--a pilot solar hydrogen project (existing)

- Hydrogen Fuel cell Bus at LAX (existing/proposed)
- Multi-fueling Facility at LAX (proposed)
- Hydrogen from Surplus Geothermal Energy (proposed)
- Hydrogen Fuel Cell People Mover at Palm Springs (proposed)
- Hydrogen from Wind Energy at Palm Desert (proposed)
- Hydrogen Fuel Cell Golf Carts on Roads at Palm Desert (proposed)

The proposed hydrogen corridor is similar in concept to the proposed "Sustainable Energy Centers" floated by some members of the hydrogen community. An amendment authorizing such a comprehensive "real world" community demonstration would be an important advance.

Additional Authorization for Hydrogen Fuel Cells Programs

We have been advocating additional federal funding for fuel cells for the past three years through Fuel Cells for Transportation (FCT), for which we were a founding member. Fuel cells represent a major leap forward towards the realization of a hydrogen energy economy. It is important that new and on-going programs in both the hydrogen and fuel cell areas be closely coordinated to maximize the use of existing funds and to avoid duplication of effort.

I would recommend that the current authorizations be increased to support additional hydrogen fuel cell programs for both transportation and stationary areas. As mentioned earlier, the cost savings from increased energy conversion efficiencies alone would represent a quick payback on federal investment in this area.

Facilitation of the Hydrogen Agenda in a Hydrogen Office

To minimize waste, improve coordination, and put the federal effort on a clear path with identifiable goals, I would suggest that the Committee consider the creation of a Hydrogen Office within the DOE to support development of hydrogen technologies. One suggestion would be an Office of Hydrogen Technology and Utilization, which would centralize and coordinate existing programs at other federal agencies and DOE (in both energy efficiency and fossil energy divisions). Funds authorized under the proposal should be added to

existing efforts--efforts that in total are minimal compared to realistic requirements or when compared to the efforts in the fossil and other fuel areas.

This new office should, within 90 days, compile, analyze and report back to the Committee, or to the panel of the Committee, on all hydrogen-related the activities being undertaken by all federal agencies. The new office would then work in concert with HTAP to accelerate the national agenda on hydrogen.

1. Burnham, L, Editor (et al.), 1993. "Renewable Energy: Sources for Fuels and Electricity." Island Press, Washington D.C.

Attachment

a:RSGMD:SPCH95

THE ROLE OF HYDROGEN IN MEETING SOUTHERN CALIFORNIA'S AIR QUALITY GOALS

Alan C. Lloyd, Ph.D.

Chief Scientist

South Coast Air Quality Management District

21865 East Copley Drive

Diamond Bar, CA 91765

USA

ABSTRACT

Despite significant improvements in the last decade, Southern California still experiences the worst air quality in the United States. Stringent emissions reductions to meet the health-related air quality standards will be required, particularly in the mobile sector. Major opportunities exist for hydrogen to meet the California zero emissions vehicle requirements. Recognizing that hydrogen is ultimately the fuel of choice to sustain a healthful regional and global environment, the South Coast Air Quality Management District is encouraging the direct and indirect use of hydrogen through information sharing, technology demonstrations, infrastructure development and incentive programs.

1. INTRODUCTION

The South Coast Air Quality Management District (District), which is a regional air quality regulatory agency based in Southern California, is responsible for protecting the health of the citizens in the counties of Los Angeles, Orange, Riverside and the non-desert portion of San Bernardino. This region, of some 14 million residents and approximately 9 million vehicles, while experiencing significant improvements, still suffers the worst air quality in the nation. Under federal mandates we are required to show that strategies can be implemented to reduce pollutant emissions so that air quality will attain the standards by the year 2010. According to a 1992 study, the health-related economic costs of adverse air quality in the Los Angeles area add up to approximately $9 billion per year (Hall, et al., 1992).[1]

While air quality has continued to improve in the last decade, the federal air quality standard for ozone is still exceeded by nearly a factor of 3, and the exposure to fine particles (PM_{10}) is still well above that recommended by the federal and state governments. Figure 1 shows a comparison of the exceedences of the various air quality standards of the District (SCAQMD, Air Quality Management Plan 1994).[2,3]

This paper will describe the major findings of the 1994 Air Quality Management Plan (AQMP), highlighting the significant emissions reductions required from the transportation sector, and then provide an overview of the major technologies being pursued to reduce emissions. Included is a discussion of the role that hydrogen can play, and the efforts underway to build a hydrogen infrastructure. Based upon our experience in the last four or five years in encouraging the use of alternative, cleaner-burning fuels such as natural gas, propane, methanol, ethanol and electricity, the timely attention to fuel infrastructure is a key to the successful implementation of an alternative fuels strategy.

2. 1994 AIR QUALITY MANAGEMENT PLAN

In order to attain the health-related air quality standards, the AQMP process incorporates the use of sophisticated air quality models, specifically adapted to the District region, to relate emissions to air quality. The current inventory, together with the major contributing sources, are shown in Table 1 (SCAQMD, Air Quality Management Plan 1994). This shows that the major contribution comes from transportation sources, both the light- and heavy-duty sectors. The two major pollutants of concern are reactive organic compounds (ROC) and nitrogen oxides (NO_x), which are precursors to both ozone and fine particulate matter (PM_{10}). NO_x and ROC emission reductions of over 70% will be required, with potentially larger reductions in NO_x required to show attainment of the California PM_{10} air quality standard. This NO_x reduction target poses an extremely tough challenge because most of the additional emissions will be required to be extracted from the heavy-duty portion of the transportation sector. The light-duty sector emissions are being reduced by the California Low Emission Vehicle/Clean Fuels regulations passed in 1990. This pioneering regulatory action includes the mandate for zero-emission vehicles commencing with 2% of new car sales in 1999, and increasing to 10% in 2003 (CARB, 1990).[4]

3. OPPORTUNITIES FOR HYDROGEN

The above-mentioned need for stringent major emission reductions from mobile sources offers significant opportunities for cleaner burning alternative fuels and zero- and near-zero emission technologies. The heavy-duty sector offers the most room for improvement in the future since existing regulations are not nearly as strict as light-duty vehicle regulations. For example, Small and Kazemi (1995)[5] calculate that the air pollution costs of operating the average automobile in Los Angeles in 1992 was about 3 cents per mile and will be approximately half of that in the year 2000. For heavy-duty diesel trucks, the corresponding numbers are approximately 53 cents a mile, reducing to about 35 cents a mile by the year 2000.

Currently, vehicle miles traveled in the District by the light-duty sector are calculated to be approximately 269 million miles per day, while the vehicle miles traveled by heavy-duty vehicles are estimated to be about 23 million miles per day. This accounts for a daily consumption of about 15 million gallons of gasoline and 2.5 million gallons of diesel. Over the next 15 years, gasoline and diesel consumption are expected to increase by 12% and 23%, respectively.

Given the substantial emissions reductions required by the AQMP, and the parallel need to sustain economic growth, it is clear that advanced air pollution control technologies will be required. One can argue that global environmental issues will similarly demand increasingly clean technologies, ultimately leading to

zero-emission, sustainable energy pathways. Figure 2 shows the human population and the number of motor vehicles for selected nations in the world. It is evident that if countries such as China and India show the same growth in motor vehicles as the United States and Japan, it is unlikely that the global atmosphere can sustain the same technologies and fuels that created large automobile populations in the advanced countries.

Hydrogen can play a key role in addressing both the regional and global issues mentioned above. Because it is a non-carbon renewable fuel, hydrogen is widely accepted as the ultimate fuel of choice. In the District, efforts have been made to pursue both advanced technologies (including zero emissions) and cleaner burning alternative fuels (SCAQMD, TAO, 1994).[6] These have included reformulated gasoline, natural gas, propane, methanol, ethanol and hydrogen. The work the District has carried out to support natural gas and methanol programs, particularly to encourage infrastructure, is seen as a direct benefit to hydrogen since both of these fuels can be reformed and thus are precursors to hydrogen. In addition, the District is supporting a number of programs to implement hydrogen. While we are supporting work on the introduction of hydrogen in the internal combustion engines, we feel that the greatest benefits will be derived from using hydrogen in an electrochemical process, namely in fuel cells. The following projects provide examples of the work that the District has supported or is supporting, directly or indirectly, involving hydrogen:

- Demonstration of a solar-hydrogen plant in tandem with a hydrogen filling station for near-zero-emission vehicles. At the University of California, Riverside's College of Engineering Center for Environmental Research and Technology (CE-CERT), hydrogen is now being made from water using an electrolyzer directly coupled to a photovoltaic array. The hydrogen is being used to power a converted pick-up truck to provide very low emissions.

- The District has created a Hydrogen Task Force charged with exploring ways to integrate the use of hydrogen into the fuels and energy mix of Southern California. The Task Force is made up of members from the public and private sectors focusing on key issues needed to expedite the use of hydrogen, e.g., addressing key economic and infrastructure aspects. The Task Force also serves as a forum to exchange the latest technical information on hydrogen.

- Ballard Power Systems has successfully demonstrated a zero-emissions pure hydrogen PEMFC shuttle bus. Supported by the District, Ballard has entered into a multi-year Phase 2 effort to develop at least three 40-foot New Flyer buses with an improved PEMFC stack and regenerative braking. Ballard hopes to work with New Flyer and/or another bus manufacturer to commercialize PEMFC transit buses before the end of this decade. The first phase bus will be operated at Los Angeles Airport (LAX) in real-world, inter-terminal service for a short period of time in December 1994.

- Chrysler has teamed with AlliedSignal, a Los Angeles area manufacturer of PEMFC technology and automotive components. This project, involving a direct-hydrogen PEMFC system with on-board hydrogen storage, is being co-sponsored by the District, with major funding from the U.S. Department of Energy. The first prototype vehicle is expected to be operational by 1998.

A "Clean Air Now Solar Hydrogen Project at Xerox Corporation" is in place to convert several vehicles at the Xerox facility to run on hydrogen. The hydrogen is being produced by the electrolysis of water. DOE is contributing about one half of the total of about $2.5 million for the solar hydrogen truck fleet, and the District is contributing $250,000 to the project. This is a scaled-up version of the project initiated at the University of California, Riverside at CE-CERT.

Other projects in California related to hydrogen which can contribute to air quality improvement in Southern California include:

- The Schatz Energy Research Center at Humboldt State University, which has successfully operated a solar hydrogen facility and integrated PEM fuel cell system during the last year, is working with Lawrence Livermore Labs and the City of Palm Desert to install PEM fuel cells in golf carts. These carts will be operated in the City of Palm Desert, the only city in California which permits the use of golf carts on city streets, and thus this application for fuel cells has a particular role in reducing on-road emissions as well as providing a testbed to develop fuel cell technology with vehicles. District support for this project is anticipated.

- Stanford University is expanding the use of hydrogen generated by excess electricity from geothermal production in Mexico. In a study with the U.S. Department of Energy and the Mexican government, the excess electricity would be transmitted to Los Angeles and utilized to generate hydrogen from the photolysis of water. This hydrogen can then be utilized in vehicles in the District to reduce emissions.

4. CONCLUSIONS

In the on-going challenge of substantially reducing emissions in the District to meet the health-related air quality standards, as well as in meeting global environmental challenges, hydrogen is seen as having a significant and increasing role. The District will continue with public/private partnerships to promote and accelerate hydrogen use, particularly for fuel cell applications in both the mobile and stationary sectors.

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TABLE I SUMMARY OF EMISSIONS BY MAJOR SOURCE CATEGORY
1990 BASE YEAR

AVERAGE ANNUAL DAY(TONS/DAY)

Source Category	VOC	NOx	CO	SOx	PM10
Stationary Sources					
Fuel Combustion	14	119	93	15	14
Waste Burning	1	2	5	0	1
Solvent Use	343	0	0	0	1
Petroleum Process, Storage & Transfer	109	1	4	2	2
Industrial Processes	42	1	2	1	27
Misc. Processes*	76	1	9	0	704
RECLAIM Sources	NA	93	NA	20	NA
Total Stationary Sources	585	217	113	38	749
Mobile Sources					
On-Road Vehicles	761	762	5,342	31	70
Off-Road Mobile	124	311	1,378	52	19
Total Mobile Sources	885	1,073	6,720	83	89
Total	1,470	1,290	6,833	121	838

Fig. 1: 1993 Air Quality in the South Coast Air Basin

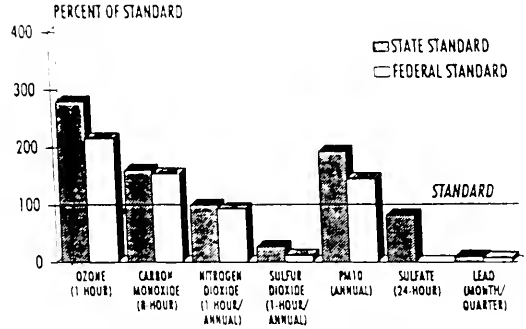
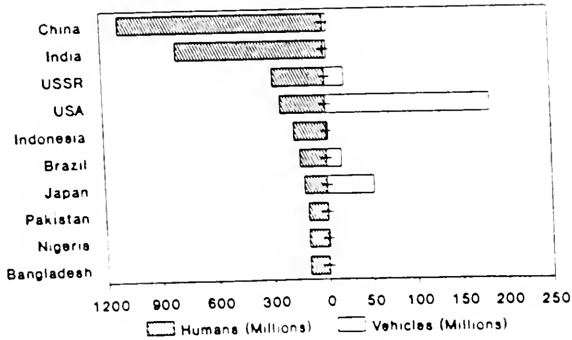


FIGURE ES-2

1993 Air Quality in the South Coast Air Basin

Despite its improved air quality over the past years, the South Coast Air Basin has the worst ozone air quality in the nation and is the only area designated as "extreme" nonattainment for ozone. The Basin is the only area in nonattainment of the federal nitrogen dioxide air quality standard. In 1992, the Basin recorded the greatest number of exceedances of the federal carbon monoxide standard in the nation. PM10 levels are also very high compared to most other areas.

Fig. 2: Human and Vehicle Populations in 10 Most Populous Nations (1988)



Source: Book of Vital World Statistics

The CHAIRMAN. Thank you, Dr. Lloyd.
Mr. Trlica.

Mr. TRLICA. Mr. Chairman and members of the committee, my name is Ed Trlica, president and chief executive officer of Energy Partners, Inc., located in West Palm Beach, Florida.

I appreciate the invitation of the committee to participate in these discussions on H.R. 655, the Hydrogen Future Act of 1995, and to offer my views as a representative—

The CHAIRMAN. Would you pull the microphone a little bit closer, please?

Mr. TRLICA. Sure.

The CHAIRMAN. Thank you very much.

Mr. TRLICA.—and to offer my views as a representative of an industry dedicated to the development of hydrogen for energy uses.

Before I address your concerns regarding the research and development needed for advancing hydrogen-based technology, I would like to tell you a little about Energy Partners and what progress we have made in responding to some of the challenges. We are a developer and manufacturer of clean and efficient power systems. The company's primary goal is to provide alternatives to conventional power systems for both stationary and transportation applications. We specialize in hydrogen fuel proton exchange membrane fuel cells which offer easy and quiet operation, high fuel efficiency, and zero emissions.

In 1989 Energy Partners designed and built a support system using a 3-kilowatt fuel cell stack to power a manned research submarine. The following year, recognizing the significance of utilizing fuel cells for transportation applications, Energy Partners began its Green Car Project in order to provide an alternative to battery-powered electric vehicles. In October of 1993 the Green Car was officially rolled out and demonstrated as a true zero emission vehicle.

Incidentally, just two weeks ago on the Discovery Channel the Green Car was featured along with the founder of energy partners, our chairman, Mr. John Perry. Not only has Mr. Perry proven to be the energy behind our efforts, he has personally contributed 90 percent of the more than $4 million in development costs associated with the Green Car.

I would be remiss if I did not also recognize and acknowledge how pleased I am to be here with Dr. Alan Lloyd representing the South Coast Air Quality Management District in California. South Coast shares a great deal of the credit for the Green Car as they provided the additional funding and, most importantly, a belief in our ability to produce the vehicle.

More recently in the transportation field, Energy Partners has entered into discussions with the city of Palm Springs, California, to provide a number of zero emission transporters for its airport. We currently are in the final stage of testing the first prototype and will be exhibiting it this month at Expo Trans '95 in Palm Springs.

In the field of stationary energy development, Energy Partners hopes to develop the Palm Springs program to include a smart building utilizing the latest energy-efficient technologies. A fuel cell system using hydrogen produced through electrolysis of water would be used for all or part of its energy requirements. The en-

ergy to split the water will be provided by wind and solar power generation.

This proposal has the potential of becoming a show place for present day technologies as well as an educational tool for industry and institutional study, which of course brings us to the focus of this hearing today. Energy Partners is a small and yet dynamic company. We are a group of dedicated managers, technicians, and scientists who constantly seem to achieve the impossible. We have been able, by virtue of this dedication and commitment and with the help of local and institutional assistance, to make great strides in advancing our technology even though Federal support has been limited.

As was noted in hearings on this legislation last year, the task before us demands greater resources than science, educational institutions, and industry can provide. While there is no question that industry must lead the way, Government must also step up to the plate with the kind of focus and support which H.R. 655 would provide. Hydrogen, an exhaustible, efficient, and pollution free, is clearly the energy of the future.

Our own commitment to educate the public and further the efforts or further the future of hydrogen for energy uses is apparent, and our actions and efforts are well known within our industry. However, it is not practical for a small business such as ours to attempt this effort alone. Even large businesses—major automobile companies come to mind—are limited in their efforts by demands to meet current business needs and satisfy their shareholders. For hydrogen to advance into the energy market, we need technologies for its production, storage, and utilization. H.R. 655 correctly identifies the need to work on all of these at the same time. It further identifies the need for demonstrations of the developed technologies. The support provided by this bill would allow the industry the financial assistance needed to continue the research and development necessary to lower present costs, thus allowing for early commercialization.

One day we will all be living in a hydrogen environment and driving a Green Car, virtually eliminating the damages caused by combustion and the pollution generated by our utility plants. When that day comes, help us to assure it is by means of technology developed here in the United States and not by foreign competitors.

Energy Partners and members of our industry strongly believe in the future of hydrogen as a redeeming fuel for a pollution-free planet. We further believe that the United States should lead the way both technically and spiritually as we seek that future.

As we face not only the dawn of a new century but the turn of the millenium, the United States, being the largest user of energy in the world, has an obligation to contribute to an environmentally responsible, renewable energy future. I hope you will favorably consider this objective and H.R. 655 which will provide the support to help make this dream a reality.

Mr. Chairman, I deeply appreciate you extending me the opportunity to appear today. Your personal support for the research and development associated with future hydrogen technology is a farseeing commitment to our Nation's energy needs. I look forward to a positive future under H.R. 655 and will be pleased to respond to

any questions you or the other members of the committee may have.

Thank you very much.

[The prepared statement of Mr. Trlica follows:]

Statement of

Mr. Edward Trlica
President and Chief Executive Officer, Energy Partners, Inc.

before the

Committee on Science
U.S. House of Representatives
February 1, 1995

Mr. Chairman and Members of the Committee: My name is Ed Trlica, and I am the President and Chief Executive Officer of Energy Partners, Inc., located in West Palm Beach, Florida. I appreciate the invitation of the Committee to participate in these discussions of H.R. 655, The Hydrogen Future Act of 1995, and to offer my views as a representative of the industry dedicated to the development of hydrogen for energy uses.

Before addressing the research and development needs to be addressed to successfully move forward in the development of hydrogen as an energy carrier, I would like to tell you a little about Energy Partners and what progress we have made in responding to some of the challenges. I believe that our story is instructive because it shows what a small, committed, company can do and the limitations we face and demonstrates very well the horizons that H.R. 655 can open, and the need it can fill.

Energy Partners, Inc. is a developer and manufacturer of clean and efficient power systems for a variety of uses. The Company's primary goal is to provide alternatives to conventional power systems for both stationary power production and transportation applications. We specialize in hydrogen fueled, Proton Exchange Membrane (PEM) fuel cell power units which offer easy and quiet operation, high fuel efficiency, and zero emissions.

In 1989, Energy Partners designed and built a support system incorporating a 3 kilowatt Proton Exchange Membrane fuel cell stack to power a manned research submarine. This program was internally financed as a proof-of-concept vehicle with no intent to commercialize it as a product.

The following year, recognizing the significance of utilizing fuel cells for transportation applications, Energy Partners began its ***Green Car*** project in order to provide an alternative to "battery powered" electric vehicles. In October, 1993, the ***Green Car*** was officially rolled out and demonstrated as a true Zero Emission Vehicle (ZEV). This proof-of-concept automobile operates on three stacks of 60 cells each, providing a total energy package of 15 kilowatts. A battery bank is used for periods of peak acceleration, thereby qualifying it, technically, as a hybrid vehicle.

Incidentally, just two weeks ago, on The Discovery Channel's "Next Step" program, highlighting scientific and technological developments for our future, the ***Green Car*** was featured, along with the founder and spirit behind Energy Partners, our Chairman, John Perry, Jr.. Mr. Perry is not only the "energy" behind our efforts, he has personally paid ninety percent of the more than 4 million dollars in development costs associated with the ***Green Car***. He has also spent over $25 million of his own money over the years in an effort to develop low cost, renewable, environmentally sound energy sources. We are, of course, extraordinarily proud of, and grateful for, that commitment; but it is also the reason that I feel comfortable sitting before you speaking of how Energy Partners' experience is a tale of a future in need, not an industry needing a hand-out.

I would be remiss if I did not also recognize and acknowledge how pleased I am to be here with Dr. Alan Lloyd, representing the South Coast Air Quality Management District in California. South Coast shares a great deal of the credit for the *Green Car*, as they provided the additional funding, and most importantly, a belief in our ability to produce the vehicle which achieved the objectives set down.

In the period since the initial roll-out of the ***Green Car***, we have advanced our expertise and capabilities in the manufacturing of fuel cells to the point of making the original ***Green Car*** stacks obsolete. Our present technology provides for the removal of one stack, integrating its cells into the remaining two, reducing the weight and cost of the power pack. Our research indicates further reductions are possible by eliminating the internal humidification and using a simple external mechanism. These advances were supported in part by funding from the State of Florida Energy Office, through a program designed to expedite product commercialization.

Without this support, and the continued personal commitment by Mr. Perry, we would not be making these forward strides. Instead, we would be losing ground against

European, Asian, and North American (yes, Canada has an active hydrogen research and development program) competition, programs substantially supported by government funding.

More recently, in the transportation field, Energy Partners has entered into discussions with the City of Palm Springs, California, to provide a number of Zero Emission Personnel Transporters for its airport. We are currently in the final stage of completing the first prototype and will be exhibiting it this month, at Expo Trans '95, in Palm Springs. The fuel cells and the system, as well as all modifications to the carrier, have been financed entirely by Energy Partners.

In the field of stationary energy development, we hope to expand our efforts to include a "Smart Building" for the City of Palm Springs, utilizing the latest energy efficient technology. A stationary fuel cell system, using hydrogen produced through electrolysis of water, would be used for all or part of its energy requirements. The energy to split the water will be provided by wind and solar power generation. This proposal has the potential of becoming a showplace for present day technologies as well as an educational tool for industry and institutional study. In order to pursue these high-technology efforts, our industry looks to the support of State and Federal government agencies, support which could be provided under H.R. 655.

In our effort to continue to advance the state of the art, Energy Partners has delivered two laboratory systems. The first went to a Materials Research Laboratory, in Australia and the second went to a Nuclear Research Center located in Mol, Belgium. These units were constructed and delivered at no profit. They were and are, another step in our continuing effort to aid worldwide acceptance of hydrogen as a sustaining fuel.

In the last quarter of 1994, Energy Partners entered into a "not for profit" agreement with the Energy Technology Engineering Center (ETEC), a Department of Energy laboratory in California, to further their knowledge of PEM fuel cells. Without charge, Energy Partners provided a fifteen cell stack and system for their use and will deliver a second unit in late March of this year.

Which, of course, brings us to the focus of this hearing today. As I noted, Energy Partners, a small and yet dynamic and wide ranging visionary in the energy field is largely supported by Mr. Perry, a successful entrepreneur who believes strongly in "giving

something back" and in the need for environmentally sound energy sources. We are a group of dedicated manager, technicians, and scientists who constantly seem to achieve the impossible. We have been able, by virtue of this dedication and commitment and with the help of local and institutional assistance, to make great strides in advancing hydrogen technology. Available Federal support is limited and diffused, even given the fact that various Federal agencies do provide assistance. It is, however, frequently associated with generic energy development programs, and often based on the need to provide hybrid or specialized results.

We are grateful to you, Chairman Walker, for your personal interest in, and support for research and development of hydrogen for energy uses. We recognize that some specialized support has been available under the provisions of P.L. 101-566, the Spark Matsunaga Hydrogen Research, Development and Demonstration Program Act of 1990. Those effects have amply demonstrated that, with a small and sharply focused investment in research and developmental technology, advancement can be made in the use of hydrogen based technologies.

The hydrogen energy research and development industry recognizes that the fuel which powers the sun, is as renewable as rain and as abundant as the water which covers most of the surface of our earth. Therefore, producing virtually no pollution is the promise of the future. Recent advances in non-fossil based electricity production photovoltaic cells which takes advantage of the energy of the sun, offer promise that the cost of hydrogen production will soon be within reach of existing fuel sources. That promise, and the advances we are making in the size, cost, and efficiency of hydrogen-based energy devices, are lighting and paving the highway to the 21st century. Photovoltaic energy alone will rely on storage systems which are inherently polluting, battery disposal, for example. We are all aware of the problems associated with nuclear energy production and use; we are also, thankfully, aware of the power of the sun, the abundance of water, and the promise they hold for the future.

Programs, and dreams yet undreamed, are the future of hydrogen technology, a future to which this Committee, this Congress, with the support for H.R. 655, can make a major, and visionary contribution.

As was noted in hearings on this legislation last year, held before the Subcommittee on Energy, for which I was pleased to provide a short statement, the task before us

demands greater resources than science, educational institutions, and industry can provide. While there is no question that industry should lead the way, government must also "step up to the plate" with the kind of focus and support which H.R. 655 would provide.

Under then-Chair Congresswoman Marilyn Lloyd, and with the support of many of the Members who are here today, most especially current full Committee Chairman Bob Walker and then Committee Chairman George E. Brown, Jr., a version of today's bill was reported from the Committee and passed the House as part of the Hydrogen, Fusion, High Energy and Nuclear Physics Research Authorization. America needs to see this type of commitment coming from government--the cost of the esoteric research and materials, the quantum leap in our thinking on the next generation of fuels, cannot be met without a national strategy and national support.

The hydrogen industry, about which I am, of course, prejudiced, promises the cleanest, safest, and most efficient solutions to many of the energy needs of the 21st century, the dawn of the third millennium.

Hydrogen, inexhaustible, efficient, and pollution free, is clearly the energy of the future. Energy Partners'commitment to educate the public and further the future of hydrogen for energy uses is apparent, and our actions and efforts are well known within our industry.

However, it is not practical for a business such as ours to attempt this effort alone. Even large businesses, the major automobile companies come to mind, are limited in their efforts by the demands to meet current business needs and satisfy shareholders.And, if I may be just a bit parochial here, I hope that the Committee will consider carefully the hundreds of small businesses such as Energy Partners as it creates a history for H.R. 655. In the competition for scarce governmental and institutional resources, we are at something of a disadvantage.

As we are all aware, Federal budget pressures will likely reduce available support and create even greater competition for what Federal funding is available. This Committee is to be especially commended for its foresight in focusing on hydrogen R&D needs in the face of those budget pressures. I hope you can devise a way to see that visionaries like John Perry and Energy Partners have a place at the table.

Statement of Edward Trlica, Energy Partners, Inc.

Far too often, support for hydrogen R&D is lost in the generic pursuit of "alternative fuels" or subsumed in the search for "electricity-powered" devices and is lost in the search for the "perfect storage battery." We already have that perfect storage system, it's called water, and can be found all around us. Help us to unlock its potential, to harness its power in the cleanest, most efficient, most powerful ways imaginable.

One day we will all be living in a hydrogen-powered environment, it is the fuel of the future, and driving a "green car," virtually eliminating the damage the internal combustion engine and today's electrical energy production plants have visited on our surroundings.

While one may question the advisability of environmental management by government mandate, no one can question that energy production and transportation emissions, using current fuels, place a burden on our environment. More importantly, of course, there is absolutely no question that the fossil-based fuels on which we rely today will, without fail, be gone tomorrow. We must plan for that tomorrow and we must do so now.

Energy Partners, and members of our industry, strongly believe in the future of hydrogen as a redeeming fuel for a pollution free planet. We further believe that the United States should lead the way, both technologically and "spiritually" as we seek that future. Hydrogen energy technology has been on the horizon for more than a century. Fuel cells, for example, go back to the middle of the nineteenth century. Now, as we face not only the dawn of a new century, but the turn of the millennium, the United States, the largest user of energy in the world, has an obligation to contribute to an environmentally responsible, renewable energy future. I hope you will favorably consider this objective and the Hydrogen Future Act of 1995 which will provide the support to make this dream a reality.

Mr. Chairman, I deeply appreciate your extending me the opportunity to appear today. Your personal support for the research and development associated with future hydrogen technology is a far-seeing commitment to our nation's energy needs. You, and Vice Chairman George E. Brown, Jr., of California, are to be commended for your foresight. I look forward to a positive future under H.R.655, and I am prepared to respond to any questions you or the other Members of the Committee may have.

The CHAIRMAN. Thank you Mr. Trlica.

Dr. Williams.

Mr. WILLIAMS. Mr. Chairman and members of the committee, my name is Robert Williams. I am a senior research scientist at Princeton University Center for Energy and Environmental Studies where I head a research group on Energy technology assessment and energy policy analysis. I am pleased to have the opportunity to comment on H.R. 655.

Since the late 1980's we have been giving increasing attention to energy strategies that emphasize hydrogen and the technologies that would use hydrogen. I believe that hydrogen can and will play major roles in the energy economy in the 21st century and strongly support the goals and central thrust of H.R. 655.

My oral testimony is oriented toward a discussion of hydrogen in a broad energy policy context framed by the major challenges facing the global energy system. The major drivers that will shape the course of energy in the 21st century are energy insecurity, local and global environmental problems, and the growing demand for energy services in the developing world. All other issues will be dwarfed by the magnitude of these challenges. And hydrogen has a promising future as an energy carrier because it offers the potential for dealing with all of these challenges simultaneously, potentially at competitive cost and without the heavy regulatory burdens that would be required to bring conventional technology in line with societal goals for energy quality—environmental quality.

I will not elaborate on energy insecurity and environmental challenges in my oral statement as the issues are generally familiar to the members of the committee, but I will briefly comment on the need for expanded energy in developing countries. In the coming decades most of the world's incremental energy requirements will be coming from the developing world. Meeting the rapidly expected growth in demand for energy in environmentally acceptable and energy secure ways poses major technological challenges for potential suppliers. They will not get away with offering just more of the same. Instead, they will have to innovate in fundamental ways. Hydrogen and various hydrogen energy carriers derived from a wide variety of primary energy sources can play major roles in meeting these challenges.

Meeting the expected rapidly growing energy needs in new ways also offers major market opportunities, and if the U.S. energy industry is not gearing up to serve this rapidly growing global market for innovative energy supply and end use technologies that will be able to meet tough environmental and energy security constraints, it will become a minor player on the world energy scene.

What will the global energy future look like? Until recently the established wisdom has been that the energy future will be just a larger version of the energy system at present which is dominated by the use of fossil fuels. But this is changing very dramatically.

In looking to the middle of the next century, two recent studies that I describe in my testimony, written testimony, one by the Shell International Petroleum Company and another that I was involved with which was prepared as an input to the United Nations Conference on Environment and Development in 1992, envisaged that in a world characterized by rapid economic growth and an eco-

nomic climate conducive to innovation, renewable energy would account for more than half of total primary energy use in the world.

Why are these studies so bullish about renewable energy? It is not because of any imminent prospect of running out of fossil fuels. Rather, it is partly because of the dramatic progress that has been made during the 1980's and early 1990's with regard to a wide range of these technologies. And, much more importantly—in addition, and, much more importantly, it is because of the recognition on the part of the constructors of these scenarios that renewable energy technologies have characteristics such that, once they are successfully launched in the market, propelled to a large extent by environmental drivers, fossil fuel technologies will probably be unable to lower costs as quickly as will be possible for many of these renewables.

Why is this? A key aspect of many renewable energy technologies is their small unit size and relative simplicity which facilitates cost cutting. Most renewable equipment can be constructed in factories where it is easy to apply modern manufacturing techniques that facilitate cost reduction. The small scale of the equipment also facilitates cost cutting through learning by doing, so that many generations of marginal technological improvements can be introduced in short periods.

For many of the renewable energy supply—other renewable energy supply technologies and end-use technologies, major innovations of the same kinds—that offer the same kinds of benefits with regard to environment and the economy as is argued for hydrogen in H.R. 655, and just as the introduction of hydrogen along with fuel cells for transportation would make it possible to meet air quality goals with new technologies that obviate the need for complicated and costly controls, so also would it be possible to meet environmental goals without the need for cumbersome control technologies with many other advanced renewable and energy-efficient technologies.

Despite the dramatic progress that has been made for a wide range of new energy technologies that address the outstanding challenges facing the energy system in the 21st century, the prospects are not good for making significant continuing progress in this area because of a rapidly unfolding crisis in energy R&D.

To begin with, it should be recognized that the energy industry is by no means in the R&D "big leagues". Compared to an average rate of expenditures on R&D of about 5 percent of gross sales for all R&D-performing manufacturing companies in the United States, the average rate of investment in the energy industry is less than 1 percent of gross sales, about the same as what it is in the primary metals industries. And there is solid evidence that in the private sector the long-term R&D in the energy area is in sharp decline.

Largely as a response to intense competitive pressures from independent power producers, the electric utility industry is cutting back sharply on long-term R&D. And the same thing is happening in the oil industry. For the major oil companies, total energy R&D has hovered around 0.7 percent of sales over the last decade, but long-term R&D as a percent of total R&D has fallen continuously from 28 percent in 1982 down to 11 percent in 1993.

The sharp decline in long-term energy R&D in the oil industry in particular is an inauspicious signal for the embryonic hydrogen energy industry, the nurturing of which is a goal of H.R. 655. It is bad news because the oil industry is the home of much of the chemical process technology expertise that will be needed for the production systems for hydrogen, and hydrogen—and various hydrogen carriers for the foreseeable future. It will be difficult to reverse the ongoing trend away from long-term R&D in the energy industry because of the importance of experience as well as training and ensuring the success of the innovative process.

A colleague of mine in a major U.S. oil company describes the virtual irreversibility of what is happening as "cutting down our technological rain forest". Successful R&D requires a long-term financial commitment that is shielded from the vagaries of short-term market conditions, and as all on this committee know well, the Federal energy R&D has been cut back sharply since 1978, the year the Department of Energy was created.

While the Hydrogen Future Act can help remedy this crisis, by itself it will be far from adequate because the U.S. is clearly not gearing up an energy R&D effort in both the private and the public sectors commensurate with the challenges posed by the energy needs of the 21st century. We need to rethink the whole energy R&D process.

I don't have the answer as to what the appropriate level of overall energy R&D funding should be and what specific priorities should be within these budget constraints, but I would like to conclude my testimony by offering preliminary guidelines for the construction of a new program.

First, I think it is extremely important that decision-makers reach a consensus of what the goals of energy policy should be for the overall R&D effort, and I would argue in light of my introductory comments that high priority should be given to technologies that are inherently safe and clean to the extent that burdensome regulations to ensure compliance with safety and cleanliness goals will not be needed if the technologies prove to be successful, to technologies that make it possible to avoid being overdependent on Middle East oil, and to technologies that are relevant to developing country needs.

Secondly, it is desirable to have a diversified R&D investment portfolio subject to the overall budget constraints. In this regard, it should be noted that emphasis on relatively small-scale technologies—for example, in the range 10 kilowatts to 150 megawatts in the case of electricity—would make it possible to have a diversified portfolio even with tight fiscal constraints, as the energy R&D cost per technology is often relatively modest in relation to costs for large systems.

Third, it is desirable to pursue and give priority to technologies that can meet multiple market needs.

Fourth, a new model for improving energy technology transfer is needed, one that actively involves potential users at a very early stage in the R&D process.

Fifth, it is desirable to isolate the funding for R&D from funding for commercial demonstrations even though it is desired to integrate these activities organizationally. Budgetary isolation is need-

ed because of the risk that in times of tight budgets there is a tendency to raid R&D budgets in order to find support for the more glamorous and generally much more costly demonstration efforts.

And finally, new mechanisms are needed for funding R&D that simultaneously avoid, first, the difficulty that private firms find in appropriating the benefits of R&D and, second, the difficulty the Federal Government has in providing the funding resources needed to support the overall effort. Perhaps a modest tax on some environmental effluents from conventional technology systems might be imposed as an alternative to a regulatory approach for dealing with these effluents, with the revenues from the tax earmarked for energy R&D on inherently clean and safe technologies.

Note, however, that such a tax—however such a tax might be constructed, it would have a practically negligible effect on energy prices while having a powerfully effective—being powerfully effective in advancing innovation goals if the resources are wisely managed.

An energy R&D program that is funded at one and a half times the present program could be supported by a program costing just one-half of 1 percent of retail expenditures on energy in the United States. Of course, if a tax is not possible along these lines, the needed resources might also be attained by eliminating permanent energy subsidies that still persist in our economy and redirect these resources to needed energy R&D.

I thank you, Mr. Chairman for the opportunity to testify before this committee.

[The prepared statement of Mr. Williams follows:]

The Energy Policy Context for the Hydrogen Future Act of 1995

Hearing Before the Committee on Science
US House of Representatives

1 February 1995

Dr. Robert H. Williams
Senior Research Scientist
Center for Energy and Environmental Studies
Princeton University
Princeton, NJ 08544

Mr. Chairman, Members of the Committee: I am honored to have the opportunity to testify on HR 655, The Hydrogen Future Act of 1995. I am a Senior Research Scientist at Princeton University's Center for Energy and Environmental Studies, where I head a research group on energy technology assessment and energy policy analysis. For the last 25 years I have been been exploring the energy future--assessing the promise of and prospective problems posed by a wide range of energy technologies and strategies. A biographical sketch is attached as Appendix A to my testimony.

Since the late 1980s our Princeton research group has given increasing attention to energy strategies that emphasize various hydrogen carriers and the technologies that would use hydrogen [see, for example, Ogden and Williams (1989), Williams (1993), Williams (1994a), Ogden and Nitsch (1993), Johansson *et al.* (1993a), Williams *et al.* (1994)]. I believe that hydrogen can and will play major roles in the energy economy of the 21st century. The bulk of my testimony is oriented toward a discussion of hydrogen in a broad energy policy context framed by the major challenges facing the global energy system. Most of my comments relating to the detailed provisions of HR 655 are presented in Appendix C attached to my testimony.

The Challenges Posed by Energy in the 21st Century

The major drivers that will shape the course of energy in the 21st century are energy insecurity, local and global environmental problems, and the growing demand for energy services in the developing world. All other issues will be dwarfed by the magnitudes of these challenges. Hydrogen has a promising future as an energy carrier because it offers the potential for dealing with all of these challenges simultaneously, at competitive cost and without the heavy regulatory burdens that would be required to bring conventional energy technology in line with societal goals for environmental quality.

The Threat of Energy Insecurity. Alternatives to oil in transport are needed because most of the remaining low-cost oil resources are in the Middle East. The US Geological Survey projects that even under conditions of maximum potential oil production in non-OPEC regions, OPEC's share the world oil market will increase by 2015 once more to over 50%, the share it had 1973-1979 (Fig. 2). Moreover, the Shell International Petroleum Company projects that total world oil production will probably peak during 2020-2030 and subsequently undergo slow decline (Fig. 1).

Hydrogen and/or various hydrogen carriers[1] can be produced from a variety of feedstocks, including

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[1] A hydrogen carrier is an alternative energy form that can be converted to hydrogen at or near the point of use. Two such carriers that could be converted into hydrogen onboard motor vehicles are methanol and sponge iron. Methanol would be reacted with steam to form a gaseous mixture of hydrogen and carbon dioxide:

$$CH_3OH + H_2O_{(g)} \text{ ---> } H_2 + CO_2,$$

while sponge iron would be reacted with steam to form hydrogen plus rust:

$$3Fe + 4H_2O_{(g)} \text{ ---> } Fe_3O_4 + 4H_2$$

In both cases the hydrogen generated could be used by a fuel cell. As the use of sponge iron as a hydrogen carrier is a relatively unfamiliar notion, I have included a brief technical description of the technologies that would be involved as Appendix D attached to my testimony. As a liquid and a solid, respectively, these hydrogen carriers are inherently easier to transport and store than gaseous or liquid hydrogen, though their adoption would pose other technical or industrial organizational challenges.

natural gas, biomass residues (MSW, crop residues, forest product residues), biomass grown on dedicated energy farms (eg. fast-growing trees, perennial grasses), and coal (Williams *et al.*, 1994) and ultimately even from electrolytic sources (Ogden and Nitsch, 1993). If hydrogen and/or various hydrogen carriers are used with end-use technologies such as fuel cells that take advantage of hydrogen's special qualities, the prospects are good that they would be competitive with conventional energy sources (Williams, 1993, 1994a). Diversification of the transport fuel system to include hydrogen and/or hydrogen carriers derived from a variety of sources would bring competition to transport fuel markets that would help bring stability to liquid fuel prices and reduce the risks associated with overdependence on Middle East oil.

Environmental Challenges. Energy-related local, regional, and global environmental problems will require burdensome regulations to ensure compliance with policies designed to meet clean air and other environmental goals, if conventional energy technology continues to be the norm.

For example, Shell projects that by 2020 there will be more than 1 billion cars in the world (Fig. 3), more than half of which will be outside of OECD countries. The intense road traffic in urban centers of the developing world in particular will create serious urban air pollution problems if road transport continues to be based mainly on the oil-burning internal combustion engine. Regulations would mandate the use of costly and difficult-to-maintain control devices, but compliance with the regulations would be difficult to enforce. Such problems could be circumvented if policies were adopted to promote a shift to fuel cell vehicles powered by hydrogen and/or suitable hydrogen carriers--as such vehicles would be pollution-free or nearly pollution-free, without the use of any control devices.

The problem of global warming may require that the world find ways to achieve deep reductions in emissions of carbon dioxide. The long-term (several century)implications of the near-term (next century) buildup of greenhouse gas concentrations in the atmosphere are especially worrisome (see Appendix E). The use of hydrogen and/or hydrogen carriers derived from a low-carbon feedstock such as natural gas,[2] a carbon-neutral feedstock such as biomass grown on a sustainable basis, and various non-carbon-based electrolytic sources would be enormously helpful in achieving such deep emissions reductions. If such fuels were used in fuel cells, there are good prospects that these deep reductions could be achieved without increasing the costs of energy services (Williams, 1993; 1994a).

The Need for Expanded Energy Services in Developing Countries. In the coming decades most of the world's incremental energy requirements will come from the developing countries. More than 90% of total incremental global energy requirements come from developing countries in the period through the first quarter of the next century, as envisioned in both the Shell Sustainable Growth Scenario (SGS) and the Renewables-Intensive Global Energy Scenario (RIGES) developed as an input to the 1992 UN Conference on Environment

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[2] Substantial emissions reductions could be achieved even with coal. The lifecycle carbon dioxide emissions per mile of driving a car powered by a fuel cell using coal-derived hydrogen or methanol would be about 1/3 and 1/4 less, respectively, than for a gasoline internal combustion engine car (Fig. 17).

However, hydrogen or methanol derived from biomass via thermochemical gasification would probably cost about the same as hydrogen or methanol derived from coal via thermochemical gasification (Williams *et al.*, 1994). Since lifecycle emissions could be reduced more than 90% with the biomass-derived hydrogen or methanol used in fuel cell vehicles compared to gasoline internal combustion engine vehicles (Fig. 17), a biomass option would be preferred in a greenhouse-constrained world, to the extent that biomass is available. Biomass-derived hydrogen or methanol used in fuel cell vehicles would make such efficient use of land, that biomass can play major roles in transport using this approach--in contrast to the situation with conventional biofuels such as ethanol derived from grain (see note to Fig. 3).

and Development (UNCED) (Fig. 1). Meeting the rapid expected growth in the demand for energy services in environmentally-acceptable and energy-secure ways poses major technological challenges for potential suppliers. They will not get away with offering just more of the same; instead they will have to innovate in fundamental ways. Hydrogen and/or various hydrogen carriers derived from a wide range of primary energy sources can play major roles in meeting these challenges.

Meeting expected rapidly growing energy service needs in new ways also offers major opportunities. An indicator of the magnitude of the opportunity is the expected level of expenditures on energy. At present the US accounts for about 1/4 of global energy use and spends about $1.4 billion per day on energy at the retail level. By 2050 the world may be spending up to $20 billion a day on energy, with the US spending not much more than it does at present. If the US energy industry is not gearing up to serve the rapidly growing global market for innovative energy supply and end-use technologies that will be able to meet tough environmental and energy-security constraints, it will become a minor player on the world energy scene.

The Long-Term Outlook for Global Energy Supply

Until recently, the established wisdom has been that energy system of the future will be just a larger version of the energy system of the present, which is dominated by the use of fossil fuels. But this is changing. In looking to the middle of the next century two recent studies (one by Shell and the other commissioned as an input to the UNCED--see Fig. 1 and Table 1) envisage that in a world characterized by rapid economic growth and an economic climate conducive to innovation, renewable energy could account for more than half of total primary energy use in the world (see the SGS and RIGES in Fig. 1 and Table 1), with especially large contributions coming from biomass (much of which would be grown on dedicated plantations) and intermittent renewable electric sources (wind, photovoltaic, and solar thermal electric power).[3,4]

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[3] While these two studies have the common feature of being bullish about the long-term outlook for renewable energy, the projections are very different on the demand side, with global energy demand being just half as large in 2050 in the RIGES compared to the SGS, and accordingly much lower CO_2 emissions in 2050 for the RIGES (see Table 1). The difference arises from the fact that the RIGES view of the future is for a world where there is substantial innovation not only on the supply side (as in the SGS) but also on the demand side. This is the reason for describing in the previous section the situation in developing countries as having a large potential for growth in the demand for the services provided by energy, rather than simply a demand for increased energy supplies. What is needed is the most economically sensible combination of investments in new energy supplies and energy efficiency improvements.

For example, the RIGES was constructed to reflect the expectation that hydrogen fuel cells come to play major roles in both transport and stationary applications by the year 2050. Fuel cell cars will be 2 1/2 to 3 times as fuel efficient as comparable internal combustion engine cars. Also, efficiencies of 55%-60% or more will be realised with both advanced gas turbine cycles and fuel cells in stationary power generation, compared to average efficiencies of 30-35% with today's power generating technologies. And wide use of fuel cells in distributed applications near users will make it economical to recover waste heat for space heating and cooling and water heating applications, so that very little fuel would be burned to provide low temperature heat--which is thermodynamically an extraordinarily inefficient way to use the high quality chemical energy stored in fuels.

In the construction of the RIGES it is also assumed that technological innovation is encouraged in a wide range of energy-intensive industries such as the basic materials processing industries, which will be the "engines of growth" for China and other developing countries as they evolve through their infrastructure-building periods. The prospects for major energy efficiency gains through technological innovation has been repeatedly demonstrated for these industries (Fig. 11). But the virtual cessation of growth in the demand for basic materials in the already industrialized countries (whose infrastructure-building period is over--see Figs. 9 and 10) makes these countries poor theaters for continuing innovation in

Why are these studies so *bullish* about renewables? It is not because of any imminent prospect of running out of fossil fuels. Rather it is partly because of the dramatic progress that has been made during the 1980s and early 1990s, in a period when public sector support for renewable energy R&D was generally falling in the US (Table 2). And it is partly because of a recognition on the part of both SGS and RIGES constructors that renewable energy technologies have characteristics such that, once they are successully launched in the market (propelled to a large extent by environmental drivers), fossil fuel technologies will probably be unable to lower costs as quickly as will be possible for many renewables. I will illustrate these points with brief discussions of recent progress relating to wind, biomass, and photovoltaic power, and from these examples highlight key aspects of the prospective new market dynamic offered by renewables.

Wind Power. One of the most stunning illustrations of progress relating to renewables is the sharp drop in the cost of electricity from new wind farms in the period 1985-1990 (Fig. 4). Remarkably, few of the cost reductions can be traced to improved technology. Instead cost reduction has been achieved mainly from learning-by-doing or "organizational learning," which involves standardizing procedures--i. e., getting better organized (see notes to Fig. 4). It is only in the last couple of years that major technological improvements have been introduced for wind power--improvements that make it possible now to provide electricity from wind in areas with good wind resources at about the same cost as for electricity from new coal plants (Fig. 4).

This experience will be typical for many renewable energy technologies. Their small unit size and relative simplicity facilitates cost-cutting. Most renewable energy equipment can be constructed in factories, where it is easier to apply modem manufacturing techniques that facilitate cost reduction. The small scale of the equipment also makes the time required from design to operation short, so that needed improvements can be identified by field testing and quickly incorporated into modified designs. As a result of such "learning by doing," many generations of marginal technological improvements can be introduced in short periods.[5]

Biomass Power. Shell engineers expect that cost cutting from learning-by-doing will be a key factor in quickly establishing a competitive industry for making electricity from biomass grown on plantations, using

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these industries. But if innovations are carried out in developing countries, via joint ventures with companies in the US and other industrialized countries, continuing improvements can be expected, as indicated by the large potential gains to be exploited in the steel industry (Fig. 12).

[4] The RIGES explicitly highlights hydrogen as an energy carrier--with 25 EJ/year of hydrogen produced from biomass via thermochemical gasification (the least costly source of hydrogen from renewable energy sources) and 14 EJ/year of hydrogen produced from solar electrolytic sources in 2050. Counting the 62 EJ/year of methanol from biomass in 2050 as a "hydrogen carrier," the total hydrogen/hydrogen carrier role in the RIGES in 2050 would be about 100 EJ/year--some 1/3 of the total demand for liquid and gaseous fuels or 1/6 of total global primary energy use at that time.

[5] In contrast, large conventional nuclear and fossil fuel energy facilities require extensive construction in the field, where labor is costly and productivity gains difficult to achieve. The long construction periods for these large energy systems also make learning difficult. In the 1970s and 1980s production bottlenecks arising from the practical difficulties of standardizing designs for large energy production facilities, toughening environmental regulations, and growing public opposition to the construction of new facilities often meant that energy produced by new plants was more costly than energy from old plants. In the case of nuclear power these problems were well understood 20 years ago, as articulated in an insightful analysis by John Fisher (*see Box A*), then Manager of Energy Systems Planning for General Electric's Power Generation Business Group.

new biomass integrated gasifier/gas turbine-steam turbine combined cycle (BIG/CC) technology (Fig. 5), for which demonstration projects are already underway in Scandinavia, in the Northeast of Brazil, and in several other parts of the world (Williams and Larson, 1993; Elliott and Booth, 1993).

Biomass power generation offers major *intrinsic* environmental benefits compared to coal-based power generation. Biomass is "greenhouse friendly," in that if it is grown sustainably there is no net buildup of carbon dioxide in the atmosphere associated with its production and use. And because biomass contains practically no sulfur, the high costs and complications of sulfur cleanup, which are so problematic for coal, can be avoided.

While a large fraction of the market for this new BIG/CC technology will be in the developing world (where electricity growth rates are at least 10 times as high as in industrialized countries), this technology will also be able to make significant contributions in industrialized countries. There the growing of biomass for energy on excess agricultural lands would make it possible eventually to phase out agricultural subsidies, which are now provided to farmers for not growing food, in order to prevent a collapse of food prices and to control erosion on erodable croplands. Both of these objectives could be met by instead growing biomass (e.g. fast-growing trees or perennial grasses) on these excess croplands.

Key to success of using biomass energy as an instrument for phasing out agricultural subsidies is to be able to pay the farmer a high enough price for the biomass that he can make a decent living without the benefit of a federal subsidy. That price will be determined in the marketplace by the level needed to make biopower competitive with alternative power sources; it depends sensitively on the efficiency and the unit capital cost of the conversion technology. Fortunately, the US is the world leader in a technology that can make this possible: the jet engine.

Since the end of World War II, the US Defense Department has made major subsidies to support the development of jet engines for military aircraft applications. So far, the major civilian spinoff of this military R&D effort has been the jet engine for commercial airline applications; here the world market is dominated by US suppliers. The jet engine improvements are also transferred eventually to large-scale industrial gas turbines, which are used to make electricity, mainly from natural gas in large-scale installations (power plant sizes of several hundred megawatts) at very competitive prices.

But only a modest fraction of the potential has been exploited for using these jet engine technological improvements directly in so-called "aeroderivative" gas turbines--i.e. gas turbines derived directly from jet engines. Such turbines offer high thermodynamic efficiency at modest scales (power plant sizes in the range 20 to 150 megawatts)--the ideal size range for biomass power plants, which must be kept fairly small, so as to avoid the high costs of transporting biomass long distances. Little attention has been given to optimizing these aeroderivative turbines for biomass applications. For modest incremental investment in R&D it would be possible to provide new livelihoods for both the farmer and the jet engine manufacturer (who is suffering substantially from the ending of the Cold War!), while providing the government with a politically attractive path for phasing out farm subsidies and a better return on its long-term investments in jet engine development.

Photovoltaic Power. Of all the renewable energy options, photovoltaic power is the furthest from commerical readiness for large market applications. Yet even here costs have been falling markedly, as a result of both "learning-by-doing" and technogical improvement.

Costs of photovoltaic modules fell 10-fold while cumulative production increased 1000-fold, 1976-1992. This is illustrated by a so-called "experience curve" (Fig. 6, bottom), which quantifies the rate of

technological progress by means of a so-called progress ratio (see figure caption for definition). The historical experience with photovoltaics indicates a progress ratio of about 80%, which means that for each cumulative doubling of production, costs have fallen about 100 - 80 = 20%. Such a progress ratio is typical for many dynamic industries. In recent years it has been a largely unfamiliar concept in the energy industry, but for the half century period leading up to the energy crisis in the early 1970s, electricity prices did fall generally in accord with such an experience curve (Fig. 6, top).

There are sound reasons for expecting that the historical price trend for photovoltaics can continue, as the technology is being advanced at a rapid rate, so that there are good prospects for continuing cost reduction. For example, the efficiencies of laboratory cells of promising thin-film technologies have increased substantially: for copper indium diselenide, from 6 to 17%; and for cadmium telluride, from 8 to 16% in the period 1977-1994 (Fig. 7).

Note that if the progress ratio remains fixed, costs will fall in calendar time more quickly, the faster the market growth rate in calendar time. Considerations of this phenomenon, along with the time value of money, have led me to conclude in a recent study that: (*i*) accelerated development of the photovoltaic industry through enhanced R&D support and commercialization incentives would be more profitable for society as a whole than letting the industry grow at its "natural" or free-market rate [see Appendix B and Williams and Terzian (1993)]; and (*ii*) the required R&D support and market development incentives would be a tiny fraction of the incentives needed for advancing more conventional large-scale nuclear or fossil fuel technologies.

The recently announced formation of Amoco/Enron Solar[6] and the earlier announcement that Enron plans to build a 100 MW photovoltaic power plant at attractive power costs in Nevada should be considered as a catalyst for launching a more broadly based accelerated photovoltaic development effort.

The finding that the economics of accelerated development are attractive should not be unique to photovoltaic technology; rather, it may well be applicable to a wide range of modular technologies that offer good prospects for technological improvement--such as the proton exchange membrane fuel cell, a potentially very low-cost fuel cell, the successful development of which would be a major step in moving toward a hydrogen energy economy.

Implications for Energy Planning. For many renewable energy supply technologies as well as for many innovative end use technologies (see, for example, footnote 3 and Fig. 12), major innovations offer the same kinds of benefits with regard to environment and the economy as is argued for hydrogen in HR 655.

Just as the introduction of hydrogen and/or a hydrogen carrier along with fuel cells for transportation would make it possible to meet air quality goals with new technologies that obviate the need for complicated and costly controls so also would it be possible to meet environmental goals without the need for cumbersome control technologies with many advanced renewable and energy-efficient end-use technologies.

For all such "inherently clean and safe" technologies it will be possible to achieve much greater environmental benefits than is possible by modifying (in effect with "bandaids") existing technologies that were originally introduced without environmental criteria in mind. Accordingly, a policy that government

[6] A joint venture involving Enron (both a large integrated natural gas company and a large independent power producer) and Solarex (an Amoco subsidiary that is one of the world's leading photovoltaic developers).

should seriously consider adopting is to demand that energy technologies meet tough environmental criteria for the long term, while giving industry flexibility in meeting environmental goals in the near term and providing the needed R&D support and commercialization incentives for meeting the long-term goals.[7]

This approach to environmental problem solving could simultanously yield much greater long-term environmental benefits and make it much easier for industry to embrace environmental goals than with approachs which require early responses to environmental concerns. While "fix-it-now" approaches involve trade-offs between environmental and economic objectives, "plan-for-the-long-term" approaches can use environment as a driver for technological innovation and economic growth that is more rapid on a long-term-average basis. The possibility that a longer-term approach to environmental problem-solving can be helpful to the economy arises because fundamental changes in a technology can improve simultaneously many of its attributes, including its economic performance, not just its environmental performance (see, for example the discussion of advanced steel-making technologies in the caption to Fig. 12).

The Unfolding Crisis in Energy R&D

It is generally accepted among economists that innovation is the single most important source of long-term economic growth, and that societies such as the US, which have high wages, can continue to experience high economic growth rates only if they are continuously on the technological frontier (Cohen and Noll, 1991). It is also well established that the private sector has a propensity to underinvest in R&D, because firms that invest in R&D have great difficulty appropriating the full benefits of these investments--a factor often cited as a basic rationale for government support of R&D. The need for new technologies to address major "external social costs" (i.e. costs not accounted for in market transactions) is another reason that government support for R&D is called for. The prospect of increasingly severe energy insecurity risks and local and global environmental problems certainly provides a strong rationale in this regard for energy R&D.
But what new R&D initiatives, if any, are called for in any area depends on the current state of R&D activities. For energy, the picture is not pretty.

To begin with, the energy industry is not in the R&D "big leagues." Compared to an average rate of expenditure on R&D of 4.7% of gross sales in 1990 for all R&D-performing manufacturing companies in the US,[8] the average rate for the energy industries (Table 4) was just 0.9% in 1990 (and only about 1.2% in the late 1970s, when energy costs were a major concern!)--about the same as for the primary metals industry.

In the late 1980s and early 1990s there were, for a short period, signs that the energy industry was "coming to life" technologically--especially in California, where the public and private sectors worked together to create a climate conducive to technological change in the electric power industry--a climate involving both "technology push" via support for R&D and "market pull" via various tax and regulatory measures. The favorable climate was largely responsible for major cost reductions for wind power (Fig. 4) and other renewables in that period.

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[7] The "Partnership for a New Generation of Vehicles" of the Clinton Administration and the auto producers, while it sets an energy efficiency rather than an environmental goal per se as its central mission, provides an example of how the "plan-for-the-long-term" approach might be organized.

[8] Examples of the average rate for truly innovative industries are: 8.9% for drug and medicine, 7.7% for communication equipment, 9.8% for electronic equipment, 12.8% for aircraft and missiles, and 7.8% for professional and scientific instruments.

At that time the Pacific Gas and Electric Company in particular had a dynamic and innovative energy R&D program that was pursuing a wide range of innovative energy demand and supply technologies. Especially noteworthy were the Collaborative Advanced Gas Turbine (CAGT) Project, aimed at commercializing advanced aeroderivative gas turbine technologies for stationary power applications, and PVUSA, a test-bed for a wide range of photovoltaic technologies emerging from the vendor's laboratories. PG&E was not only doing good work, but it was pioneering a new model for R&D that offered the potential for dramatically improving the rate of technology transfer from the laboratory to the market--a model in which the R&D was managed by the prospective user (in this case the utility), carried out primarily by the manufacturers of equipment, with supporting roles played by government and university laboratories.

Despite the promise offered by this new approach to R&D, the company essentially abolished its energy R&D program in the summer of 1993. So doing was not irrational. The company was facing intense competitive pressures from independent power producers and sought to cut "unnecessary" costs (such as R&D) so as to avoid losing its big industrial customers. And there was a growing recognition, that others (including the competition), would be major beneficiaries of successful R&D programs.

The story is similar for other utilities. In addition, the Electric Power Research Institute has been losing utility clients, is also cutting back on its long-term R&D, and is being forced into a restructuring in which its clients pay for a core subprogram plus selected technological subprograms of their chosing. In the process, promising technologies such as advanced aeroderivative gas turbines and renewables are attracting little utility interest: in the case of aeroderivative turbines because of the concern that others, including independent power producers, would reap most of the benefits, and in the case of renewables, because their R&D interests are shaped to a large degree by current energy market conditions, which involve very low short run marginal costs for natural gas.

Should the independent power producers instead take the lead on R&D for power generation? Unfortunately, most independent power producers are not capable of carrying out substantial programs. Many firms make heavily leveraged investments and cannot afford the risks of innovating.

Anecdotal evidence suggests that the same thing is happening in the oil industry, where many firms are "downsizing," with major staff reductions in areas that do not directly serve the goal of enhancing short-term profits--a situation that reflects in large part the stability of the world oil price at a low level of $20 per barrel or less. Statistical evidence for the major international oil companies supports such anecdotes. While total R&D has hovered around 0.7% of sales over the last decade (Fig. 8, top), long-term R&D as a percent of total R&D has fallen continuously, from 28% in 1982 to about 11% in 1993 (Fig 8, bottom)!

The sharp decline in long-term energy R&D in the oil industry is a particularly is an inauspicious signal to the embryonic hydrogen energy industry, the nurturing of which is a goal of HR 655. It is bad news, because the oil industry is the home of much of the chemical process technology expertise that will be needed for the production systems for hydrogen and/or various hydrogen carriers for the foreseeable future. This is clearly the case for diesel fuel [a promising "first-generation" hydrogen carrier for fuel cell vehicles (Fig. 16)], for hydrogen or methanol derived from natural gas (which may also play major roles as fuel cell fuels in the decades immediately ahead), and for coal (as the oxygen-blown gasifier developed by Shell and others is the key new technology needed to make hydrogen or methanol from coal). And it is probably also true for hydrogen or methanol derived from biomass, since the required chemical processing technology is very similar.

It will be difficult to reverse the ongoing trend away from long-term R&D in the energy industry,

because of the importance of experience as well as training in ensuring the success of the innovative process. A colleague in a major US oil company describes the virtual irreversibility of what is happening as "cutting down our technological rain forest." Succcessful R&D requires a long-term financial commitment that is shielded from the vagaries of short-term market conditions.

And, as all on this Committee know very well, the federal energy R&D budget has been cut back sharply since 1978, the year the Department of Energy was established. Nevertheless, I will repeat the numbers here, as the cutbacks are astonishing, no matter how they are expressed. Between 1978 and 1992, total US DOE funding for energy R&D fell (Table 3):

76% in absolute terms (in constant dollars),
83% as a percent of total total federal R&D funding, and
82% as a percent of GDP.

Moreover, considering only renewables and updating to FY '94 (Table 2), the net budget reduction was 76% in absolute terms (in constant dollar), 1978-1994.

What does all this mean? One might try to argue that a strong federal program is not needed, especially in light of the fact that so much progress was made on renewables over the last decade, despite the sharp DOE budget cutbacks. But closer inspection of the technological progress that was made in this period shows that many of these gains were made as a result of advances made outside of renewables programs. There has been substantial progress in BIG/CC technology, for example, partly as a result of advances in jet engines that can be made into aeroderivative gas turbines; but the ending of the Cold War has put a damper on this driver. Similarly, advances in the biomass gasifier technology that is to be used in BIG/CC devices have benefited from prior substantial investments in coal gasification technology development; the driver here has also stalled, with the ending of the Clean Coal Program. Likewise the "breakthrough" wind turbine technology highlighted in Fig. 4 is largely due to serendipitous improvements in variable speed ac induction motors used in "energy efficiency" applications. Similarly, the major advances that have been made recently with the proton exchange membrane fuel cell (which is being seriously considered for light-duty vehicle applications) were the result of the resurrection of this technology for prospective military submarine applications by the Canadian government in the early 1980s, when Cold War tensions focussed the attention of policymakers there on the risks of submarine warfare.

Moreover, in a major analysis (Cohen and Noll, 1991) of a wide range of case studies of experience with government support for research and development (which included, in the energy area, the Clinch River Breeder Reactor, the synfuels program, and the photovoltaics program), the photovoltaics program received substantially higher ratings than the others, and was judged to have not succeeded as well as had been hoped, largely because the funding was cut back sharply too early in the course of the program.[9]

All this leads me to believe that the US is not gearing up an energy R&D effort commensurate with the challenges posed by the energy needs of the 21st century. At the same time I am not suggesting that we turn back the clock to 1978 or 1980. The energy R&D priorities then were generally was not well matched to energy policy needs, and R&D was often carried out inefficiently, with poor prospects for technology transfer

[9] In constant 1992$, funding increased from $66 million in 1976 to a peak level of $255 million in 1980, after which it fell precipitously, reaching a low of $39 million in 1990. Since then funding has been increasing, reaching $74 milion in FY '94.

out of the laboratory into the market. We need to rethink the whole process.

Criteria for Formulating a New Energy R&D Program

I don't have "the answer" as to what the appropriate level of overall energy R&D funding should be, and what specific priorities should be within these budgetary constraints, but I offer the following as some preliminary guiding principles for the construction of a new program.

- First, decisionmakers should reach a consensus on what the energy policy goals are for the overall R&D effort. I would argue (in light of my introductory comments) that high priority should be given to:

  --Technologies that are inherently safe and clean, to the extent that burdensome regulations to ensure compliance with safety and cleanliness goals would not be needed if the technologies proved to be successful.

  --Technologies that make it possible to avoid being overdependent on Middle East oil.

  --Technologies relevant to developing country needs.

- Second, it is desirable to have a diversified R&D investment portfolio, subject to overall budget constraints. In this regard it should be noted that emphasis on relatively small-scale technologies (e.g 10 kW_e to 150 MW_e in the case of electricity) would make it possible have a diversified portfolio even with tight fiscal constraints, as the R&D cost per technology is often relatively modest in relation to costs for large-scale systems.

- Third, technologies that can meet multiple market needs should be favored.[10]

- Fourth, a new model for improving technology transfer is needed--one that actively involves potential users at an early stage in the R&D process.

- Fifth, it is desirable to isolate the funding for R&D from funding for commercial demonstrations, even though it is desirable to integrate organizationally these activities. Budgetary isolation is needed because of the risk that, in times of tight budgets, there is a tendency to raid R&D budgets in order to find support for the more glamourous and generally much more costly demonstration efforts.

- And finally, new mechanisms are needed for funding R&D that simultaneously avoid: (*i*) the difficulty the private firm finds in appropriating the benefits of the R&D, and (*ii*) the difficulty the federal government has in providing the funding resources needed to support the overall effort. Perhaps a modest tax on some environmental effluents from conventional energy systems might be imposed as an alternative to a regulatory approach for dealing with such effluents, with the revenues from the tax earmarked for energy R&D on inherently clean and safe technologies. Note that however such a tax

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[10] In the gas turbine area, for example, R&D on advanced aeroderivative gas turbines could lead to devices that serve well both potential natural gas and biomass markets, whereas exclusive focus on large-scale industrial turbines would make it difficult to use the technological advances in serving biomass applications.

might be constructed, it would have practically a negligible effect on energy prices but could be powerfully effective in advancing innovation goals, if the resources were wisely manages. An energy R&D program funded at 1.5 times the present program could be supported by a program costing just 0.5% of retail expenditures on energy in the US. Alternatively, the needed resources might be obtained by eliminating permanent energy subsidies that persist in our economy and redirect these resources to energy R&D.

Box A: The Roots of Nuclear Power Cost Escalation

A 1974 analysis by John Fisher (***Energy Crises in Perspective***, Wiley, NY, 1974)), then Manager of Energy Systems Planning for General Electric's Power Generation Business Group, of the escalation in nuclear power costs in the decade leading up to the first oil crisis provides an important insight relating to power plant construction-related problems that seems relevant for the escalation in electric power costs generally from 1970 to the mid-1980s:

> "When measured in constant dollars per kilowatt of capacity, the cost of constructing a nuclear power plant increased by perhaps 50 percent in the past decade... When power plant costs rise an explanation is required, as we expect all power plant costs to decline through the economies of scale and new technology. The environmental movement was responsible for part of the rise in nuclear plant costs, by causing various procedural delays and by requiring additional expensive safeguards to protect against hypothetical accidents. But there appears to be another cause for increasing construction costs, associated with a growing portion of high-cost field construction and a shrinking proportion of low-cost factory construction for the very large power plants now being built.. The costs associated with a shift to field from factory can more than offset anticipated economies of scale..."

Fisher pointed out that for many decades plant construction in the electric power industry followed a pattern in which part of the construction (mainly the building and the boiler) was carried out in the field and part (manufacture of the turbine, generator, and power conditioning equipment) was carried out in large factories serving many utility plants. As electric utility plant capacity doubled every decade, factory capacity also doubled, as did field construction at each site. Manufacturing and construction costs per kW_e declined in the factory and in the field, since each of these increased its scale of operations. As long as both activities grew in proportion, the economies of scale produced similar cost reductions in each, and therefore an overall cost reduction, even though the unit cost of field construction was always higher than the unit cost of factory construction. This pattern held until plant size reached about 200 MW_e and was reflected in a good fit of the average US electricity price to a 75% experience curve during most of the period up to 1970 (*see Figure 6, top*).

This trend was upset with the introduction of nuclear power. Because of the requirements for shielding and containment and other specifically nuclear features, nuclear plants were expected to be more capital-intensive than fossil fuel plants for the same rating. Since these nuclear-related costs account for a smaller fraction of the total cost at larger plant sizes, it was reasoned that nuclear plants must be built large. Accordingly, nuclear power plant capacities were built in sizes of the order of 1000 MW_e. But building larger plants requires shifting a larger fraction of total construction from the factory to less-efficient field locations, thereby raising costs.

Fisher's important insight is that the widely touted economies of scale in power plant construction are illusory because: (*i*) field construction is inherently more costly than factory construction, and (*ii*) with field construction it is never possible to move very far along the learning curve, in contrast to the situation with factory production.

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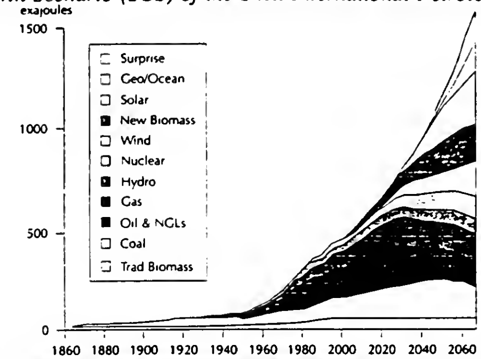
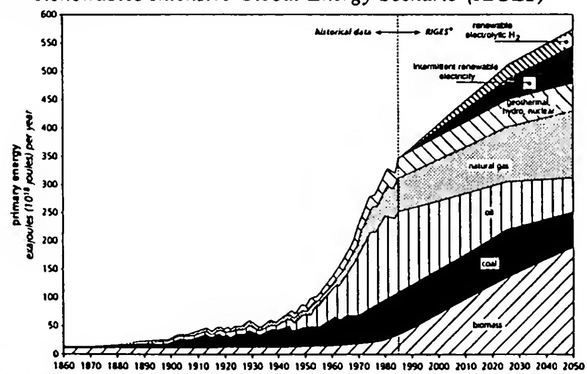
FIGURE 1. GLOBAL PRIMARY ENERGY USE *(Exajoules/year)*, HISTORY AND ALTERNATIVE PROJECTIONS

Sustained Growth Scenario (SGS) of the Shell International Petroleum Company[a]



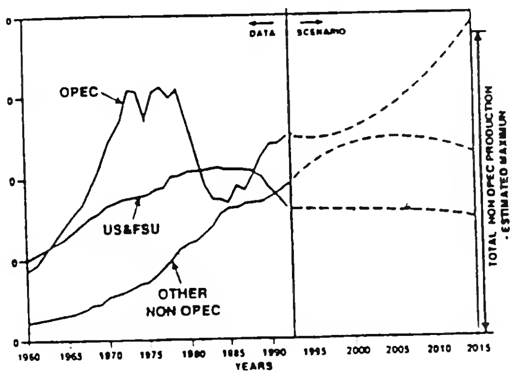
Renewables-Intensive Global Energy Scenario (RIGES)[b]



[a] P. Kassler, "Energy for Development," Shell Selected Paper, Shell International Petroleum Co., London, November 1994.

[b] T. B. Johansson, H. Kelly, A. K. N. Reddy, and R. H. Williams, "Renewable Fuels and Electricity for a Growing World Economy: Defining and Achieving the Potential," Chapter 1, pp. 1-71, in ***Renewable Energy: Sources for Fuels and Electricity***, Island Press, Washington DC, 1993.

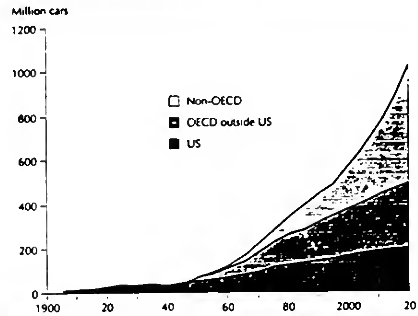
**FIGURE 2. WORLD OIL PRODUCTION:
HISTORICAL TRENDS
and
A US GEOLOGICAL SURVEY (USGS) PROJECTION
Based on
PROJECTED GLOBAL OIL DEMAND GROWTH
and
USGS ESTIMATES OF MAXIMUM PRODUCTION CAPABILITY
for NON-OPEC Regions[a]**



[a] The projection shown here is for an assumed 1% annual growth in world oil demand, from 60 million barrels/day in 1992 to 76 million barrels/day by 2015. The USGS projects that, for the US and Former Soviet Union (FSU), maximum potential production will continuously decline from present levels, while the maximum potential production in other non-OPEC regions will peak by about 2005 and subsequently decline. The shortfall in supply from these regions would be made up by increased OPEC production, mainly from producers in the Middle East, where there are abundant supplies of low-cost oil. Note that between 1992 and 2015 OPEC's share of world oil production would increase from 41% in 1992 to over 50% by 2015, thus regaining the market share it held in the period 1973-1979.

Source: C. D. Masters, E. D. Attanasi, and D. H. Root [US Geological Survey, National Center, Reston, VA], "World Petroleum Assessment and Analysis," ***Proceedings of the 14th World Petroleum Congress***, Stavanger, Norway, John Wiley and Sons Ltd., 1994.

FIGURE 3. SHELL PROJECTION OF THE GROWTH OF THE WORLD AUTO POPULATION[a]

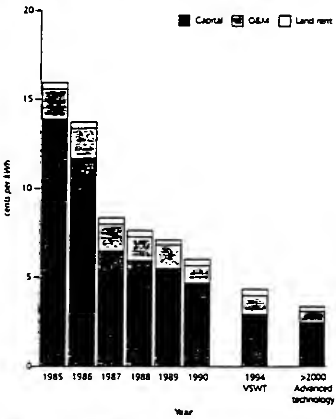


[a] This projection (P. Kassler, "Energy for Development," Shell Selected Paper, Shell International Petroleum Company, London, 1994) envisages that the world car population will grow from 450 million in 1990 (with the US accounting for about 1/3 of the total) to over 1000 million by 2020 (with the US accounting for about 1/5 of the total).

What would fuel requirements be? If these cars were run on gasoline and had the world average fuel economy of 1985 (17 mpg), oil requirements for the world's car fleet would increase from 11 million barrels/day in 1985 to 32 million barrels/day in 2020. Alternatively, suppose that all cars in 2020 had internal combustion engines fueled with ethanol derived from corn. Assuming US average corn yields, each hectare of cropland planted in corn would be able to support 2 cars. Thus some 500 million hectares of corn energy plantations would be needed to support the world's auto fleet in 2020. It may well be difficult to find this much land for such plantations. One recent study estimates that a reasonable long term target for biomass plantations worldwide is about 400 million hectares (T. B. Johansson, H. Kelly, A. K. N. Reddy, and R. H. Williams, "Renewable Fuels and Electricity for a Growing World Economy: Defining and Achieving the Potential," Chapter 1, pp. 1-71, in ***Renewable Energy: Sources for Fuels and Electricity***, Island Press, Washington DC, 1993).

There are far more efficient ways to use biomass for transport fuel. If biomass in the form of wood chips from fast-growing trees were gasified thermochemically and converted to hydrogen for use in fuel cell vehicles, some 14 cars could be supported on 1 hectare of land (assuming an average biomass yield of 15 dry tonnes per hectare per year), so that only about 75 million hectares of plantation land area would be required worldwide. For comparison, the US currently pays farmers not to grow food crops on some 30 million hectares, as a strategy for keeping food prices from falling too low and for controlling erosion. Both objectives could be met without subsidy if farmers were instead encouraged to grow cost-competitive energy crops on these excess croplands. For a detailed discussion of relative yields and energy balances for alternative biofuel strategies, see R. Williams, E. Larson, R. Katofsky, and J. Chen, "Methanol and Hydrogen from Biomass for Transportation," paper presented at Bio-resources '94 *Biomass Resources: a means to sustainable development*, Bangalore, India, 3-7 October 1994.

FIGURE 4. TREND IN THE COST OF ELECTRICITY FROM WIND[a]

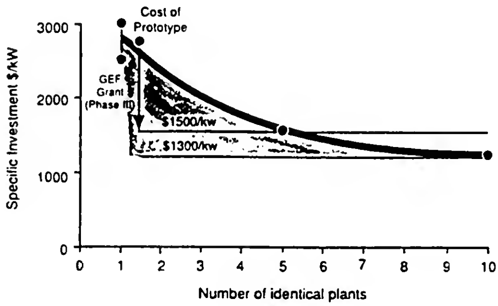


[a] Wind power costs for the period 1985-1990 are based on actual experience with wind farms in California. The cost shown for 1994 is for a new variable-speed wind turbine (VSWT) that went into commercial service in 1994; this cost is about the same as for electricity from a new coal steam-electric plant. For the period beyond 2000 the cost reflects expectations about improvements that could be realized over the next decade. Source: T. Johansson, H. Kelly, A. Reddy, and R. Williams, "Renewable Fuels and Electricity for a Growing World Economy: Defining and Achieving the Potential," Chapter 1, pp. 1-71, in ***Renewable Energy: Sources for Fuels and Electricity***, Island Press, Washington DC, 1993.

New technology played a minor role in achieving cost reductions during 1985-1990. Rather, costs fell largely as a result of organizational learning. Manufacturers learned how to exploit the economies of mass-producing standardized wind turbines. And, through better measurements of local wind resources, wind farm developers learned better "micrositing techniques" for extracting more energy from the wind with the same technology, and they learned how to schedule maintenance during periods of low wind.

The VSWT makes it possible for the rotor to turn at optimal speed under a wide range of wind conditions, thereby increasing wind energy capture, while also reducing material fatigue and maintenance costs. This technology has been brought to commercialization via a joint venture involving U. S. Windpower, the Pacific Gas and Electric Company, the Niagara Mohawk Company, and the Electric Power Research Institute, for a total development cost of $70 million. This astonishingly low development cost can be attributed largely to: (*i*) the simplicity and modularity of wind power technology generally, and (*ii*) the fact that costs for variable speed drive technology fell dramatically in the 1980s as a result of rapid growth in markets for variable speed drives for ac induction motors in commercial building and industrial applications. Variable speed drive costs have fallen to the point where it has become economically attractive to adapt the technology to wind power. Further technological improvements are expected to reduce the cost of wind power to 4 cents per kWh or less over the next decade or so.

FIGURE 5. LEARNING CURVE FOR BIOMASS-INTEGRATED GASIFIER/COMBINED CYCLE TECHNOLOGY[a]



[a] This learning curve indicates the expected trend in unit costs for biomass integrated gasifier/combined cycle (BIG/CC) technology based on a 25,000 kW_e demonstration plant that is scheduled to commence operation in the late 1990s in the northeast of Brazil. Shell researchers involved in the project expect that the costs for the first 10 units will follow a learning curve characterized by an 80 percent progress ratio (*i.e.*, the installed cost is expected to decline 20 percent for each cumulative doubling of production), based on the expectations that: (*i*) most plant assembly would take place in the factory; (*ii*) there would be minimal site preparation and foundation requirements; (*iii*) onsite construction would consist mainly of integration of standard factory-built modules; and (*iv*) there would be short time lapses between ground breaking and plant start-up. Source: P. Elliott and R. Booth, "Brazilian Biomass Power Demonstration Project," Special Project Brief, Shell International Petroleum Company, London, 1993.

For modular technologies like this, the "cost of learning" is far less than for large-scale fossil or nuclear technologies. Note that:

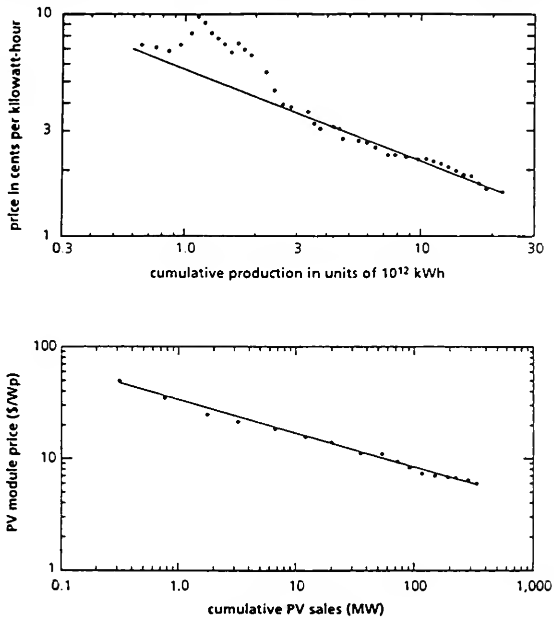
Cost of BIG/CC learning = (shaded area)*(25,000 kW_e) = $0.12 billion.

This can be compared to the cost of learning for an advanced nuclear fission technology, such as a "passively safe" design for which the size target for commercial plants is 600,000 kW_e. If this technology were to follow exactly the same learning curve for unit capital cost, then:

Cost of nuclear learning = (shaded area)*(600,000 kW_e) = $2.9 billion.

Also, it is much more difficult to "get onto" learning curves for large-scale technologies, as is indicated by the experience with nuclear power (see Box A).

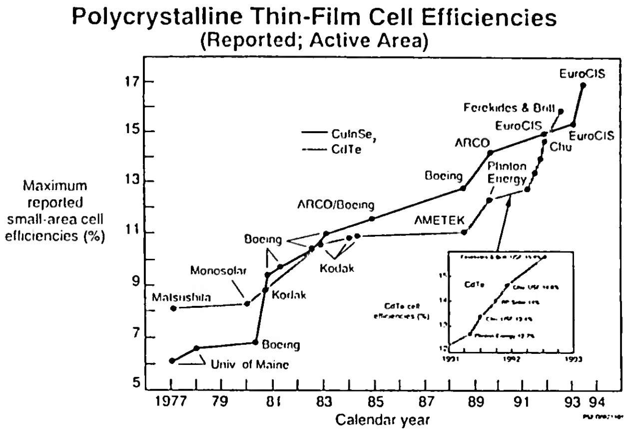
FIGURE 6. EXPERIENCE CURVES RELATING TO ELECTRIC POWER



The long-term evolution of product price for a dynamic, rapidly growing industry is typically better described as a function of cumulative production than as a simple function of calendar time. The price vs. cumulative production trend can be represented in a log-log plot by a straight line characterized by a progress ratio PR (measured in percent) such that the price declines (100 - PR)% for each cumulative doubling of production. Such a trend line, called an "experience curve," captures the cost-cutting benefits of both "learning-by-doing" for a given level of technology and technological improvements. Two experience curves related to electricity are shown here.

The top curve is the trend for the US average electricity price (in 1970 cents/kWh), 1926-1970. The trend line corresponds to a 75% progress ratio. Prices rose above the trend line in the 1930s largely because of the high fixed charges associated with electricity generation in the face of depression-diminished demand. The bottom curve, for which the progress ratio is 81.6%, tracks the worldwide average prices (in 1992 dollars per peak Watt) and sales of pv modules, 1976-1992. Data are from Strategies Unlimited, Mountain View, CA, September 1993.

FIGURE 7. TREND IN EFFICIENCIES FOR LABORATORY-SCALE POLYCRYSTALLINE THIN-FILM PHOTOVOLTAIC CELLS[a]



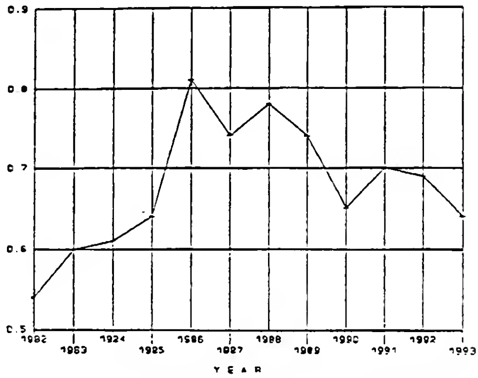
[a] Maximum stabilized efficiencies for the active area of small laboratory photovoltaic cells made of thin films of polycrystalline cadmium telluride (CdTe) and copper indium diselenide ($CuInSe_2$). These data, from Ken Zweibel, Manager of the Thin-Film Project, National Renewable Energy Laboratory, September 1993, are based on both NREL measurements and measurements reported in the literature.

Thin-film photovoltaic devices based on these and other materials (including amorphous silicon, the most advanced thin-film technology) offer the potential for realizing very low unit capital costs at moderate efficiencies. (Other kinds of photovoltaic devices have the potential for realizing higher efficiencies but at higher unit capital costs.) The potential for low unit capital cost arises because the active layers of the cells are of the order of one micron thick and thus require very little material. (Note that a typical human hair is about 90-100 microns thick.) Thus the materials cost is dominated by the costs for glass for encapsulation, wires, etc.

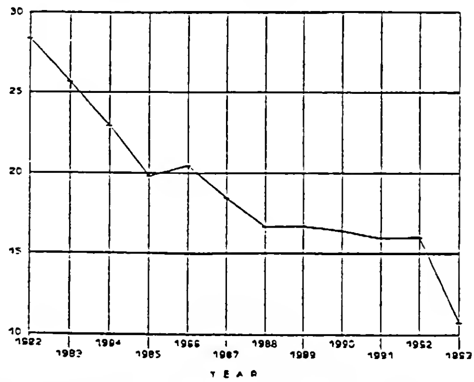
The efficiencies shown in this figure are for laboratory cells (areas of the order of 1 cm^2). Further development is needed in order to realize a 15% efficiency in large modules (of the order of 1 m^2 or more per module) and to engineer the processes for mass producing such devices. It is expected that, with an aggressive R&D effort, this could be realized by 2010.

FIGURE 8. TRENDS IN SPENDING ON R&D BY THE MAJOR INTERNATIONAL OIL COMPANIES[a]

R&D as a Percent of Sales

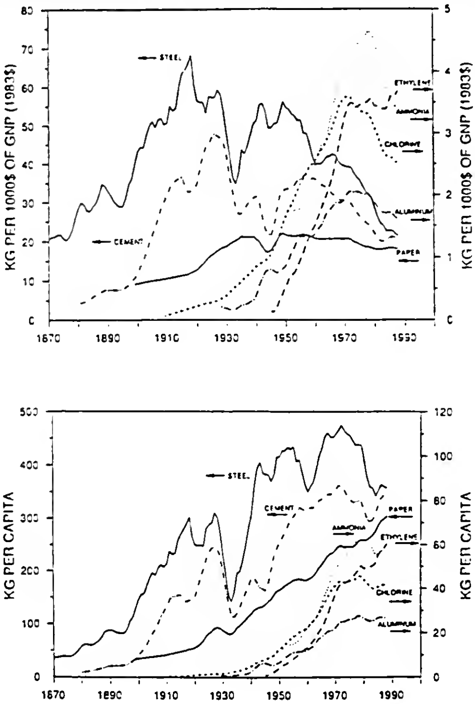


Long-Range R&D as a Percent of Total R&D



[a] Private communication from Jules Duga, Battelle Columbus Laboratories, 17 January 1995.

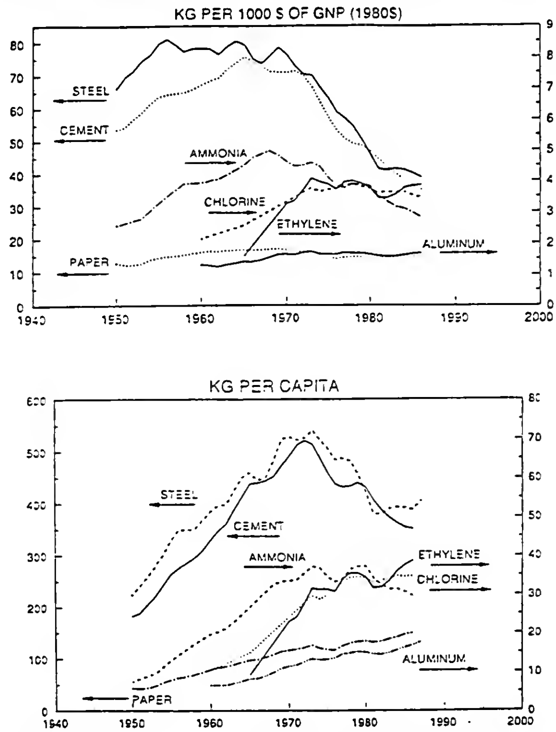
FIGURE 9. TRENDS IN THE APPARENT CONSUMPTION OF ENERGY-INTENSIVE BASIC MATERIALS IN THE UNITED STATES[a]



[a] Apparent annual consumption (production plus net imports) measured in physical terms (i.e. kilograms per year) is shown in the top graph in relation to GNP (in constant, inflated-corrected dollars) and in the bottom graph on a per capita basis. Annual data have been averaged over 5-year periods.

Source: Data presented in R. H. Williams, E. D. Larson, and M. H. Ross, "Materials, Affluence, and Industrial Energy Use," ***Annual Review of Energy***, vol. 12, pp. 99-144, 1987, have been updated through 1990.

FIGURE 10. TRENDS IN THE APPARENT CONSUMPTION OF ENERGY-INTENSIVE BASIC MATERIALS IN WESTERN EUROPE*



* Apparent annual consumption (production plus net imports) measured in physical terms (i.e. kilograms per year) is shown in the top graph in relation to GNP (in constant, inflated-corrected dollars) and in the bottom graph on a per capita basis. The data are aggregates for France, (West) Germany, and the United Kingdom. Annual data have been averaged over 3-year periods.

Source: Data presented in R. H. Williams, E. D. Larson, and M. H. Ross, "Materials, Affluence, and Industrial Energy Use," ***Annual Review of Energy***, vol. 12, pp. 99-144, 1987, have been updated through 1990.

FIGURE 11. HISTORICAL TRENDS IN MANUFACTURING ENERGY REQUIREMENTS PER UNIT OF OUTPUT FOR SELECTED BASIC MATERIALS PRODUCED THE US[*]

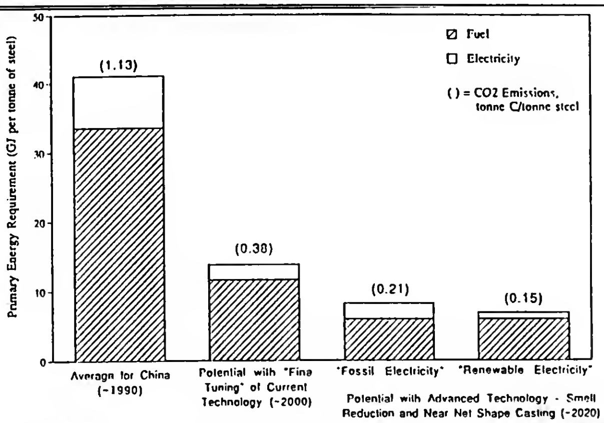
Soda Ash (Solvay Process)		Ammonia (Haber-Bosch Process)		Chlorine (Diaphragm Cells)		Raw Steel (Changing Process Mix)	
Date	Energy (GJ/tonne)	Date	Energy (GJ/tonne)	Date	Electricity (kWh/tonne)	Date	Energy (GJ/tonne)
1868	60	1917	93.0	1916	4400	1947	37.5
1894	31	1923–50	81.0	1947–73	3300	1954	32.4
1911	28	1965	52.0	1980	2400	1962	30.0
1925	17	1972	46.5			1971	27.8
1942	15	1978	41.2			1980	27.0
1970	14						

Hydraulic Cement (Wet and Dry Processes)		Ethylene Dichloride		Ethylene Oxide		Polyethelene	
Date	Energy (GJ/tonne)	Date	Index	Date	Index	Date	Index
1947	10.3	1967	100	1970	100	1956	100
1955	9.0	1973	15	1973	85	1973	40
1960	8.5			1974	79	1974	18
1965	8.2						
1971	7.5						
1978	6.8						

[*] These data show that most improvements in technology in the basic materials processing industries have been associated with substantial improvements in the efficiency of energy use. For these "energy-intensive" industries, expenditures on energy typically account for a large fraction of industrial production. Accordingly, if firms have the incentives needed to innovate, they will tend to pursue new technologies that are more energy-efficient than existing technologies.

Source: R. H. Williams, "Innovative Approaches to Marketing Electric Efficiency," pp. 831-862, in ***Electricity: Efficient End-Use and New Generation Technologies and Their Planning Implications***, B. Bodlund, T. B. Johansson, and R. H. Williams, eds., Lund University Press, Lund, Sweden, 1989.

FIGURE 12. ENERGY REQUIREMENTS FOR PRODUCING STEEL WITH ALTERNATIVE TECHNOLOGIES, COMPARED TO THE CURRENT AVERAGE TECHNOLOGY IN CHINA[a]

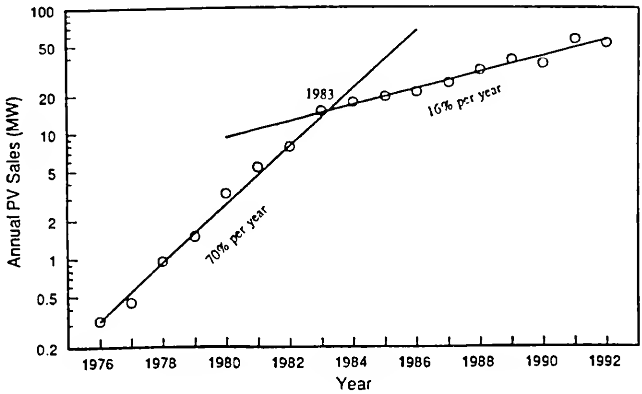


[a] At present steel making in China is very inefficient (the average amount of energy used to produce a tonne of steel is nearly twice that used in the US) and highly polluting. By fine-tuning the most energy-efficient steel-making technology currently available it would be possible to reduce energy requirements for making a tonne of steel in China by about 2/3--an option that could be practically realized for new plants by 2000.

With advanced technology (specifically, smelt reduction and near net shape casting) that could become commercially available in the period 2010-2020, unit energy rquirements could be reduced by 4/5 relative to present practice in China. Despite the dramatic energy efficiency gains made possible by this advanced technology and the associated reduced expenditures on energy, other factors would also be powerful drivers for seeking these improved technologies: (*i*) the process integration made possible by these advanced technologies would lead to lower unit capital costs and would facilitate air pollution control; (*ii*) favorable economics could be achieved at much smaller scales than is feasible with conventional technology, thus expanding market opportunities; (*iii*) the advanced tehnology makes it possible to use ordinary steam coal instead of the more costly coking coal; (*iv*) the advanced technology makes it possible to use powdered ores directly, without first having to incur the costs of pelletizing or sintering, as is necessary with conventional technology; and (v) major reductions in CO_2 emissions are possible with the advanced technology as a "bonus."

Source: E. Worrell [Dept. of Science, Technology, and Society, Utrecht University, Utrecht, The Netherlands, and currently at the Center for Energy and Environmental Studies, Princeton University], "Energy Efficient Technlogies in the Iron and Steel Industry," paper prepared for the World Energy Council as an input to a Council report on energy efficiency being prepared for the 1995 World Energy Congress, to be held in Tokyo, October 1995.

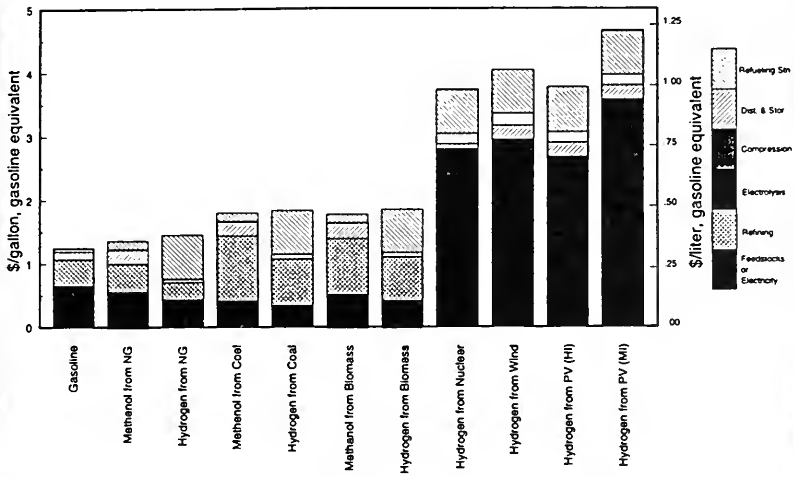
FIGURE 13. WORLDWIDE SALES OF PV MODULES, 1976-1992[a]
(MW_p per year)



[a] Source: Strategies Unlimited, Mountain View, CA, September 1993.

FIGURE 14. PROJECTED COSTS OF ALTERNATIVE TRANSPORT FUELS DELIVERED TO CONSUMERS[a]

[in $/liter ($/gallon) of gasoline-equivalent]



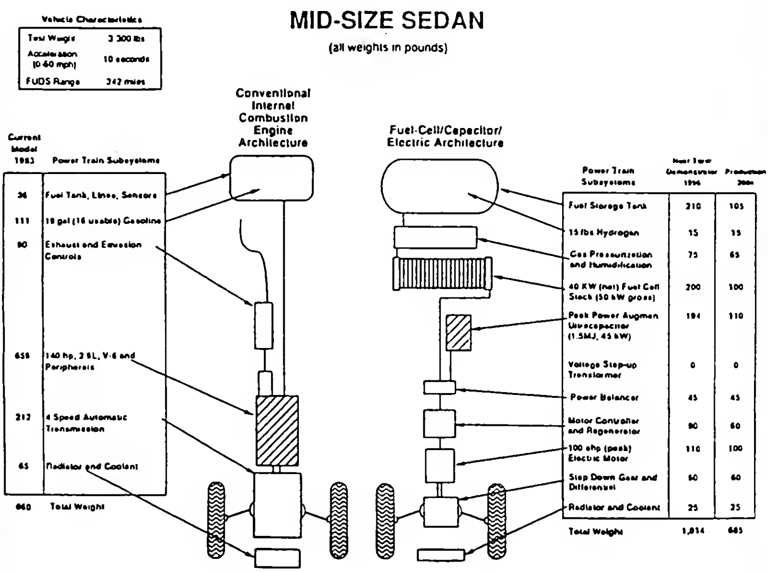
[a] The total costs shown include costs for primary production, transport, and retailing, based on primary energy prices expected for the period near 2010. For details, see: R. Williams, "Fuel Cells, Their Fuels, and the US Automobile," ***Proceedings of the First Annual World Car 2001 Conference***, University of California at Riverside, Riverside, CA, 20-24 June 1993; R. Williams, E. Larson, R. Katofsky, and J. Chen, "Methanol and Hydrogen from Biomass for Transportation," paper presented at Bio-resources '94 ***Biomass Resources: a means to sustainable development***, Bangalore, India, 3-7 October 1994.

The costs for methanol and hydrogen production from natural gas (NG) are based on steam reforming, assuming a NG feedstock cost of $3.2/MBTU. The costs for biomass-derived methanol and hydrogen are for thermochemical gasification of biomass using the Battelle Columbus Laboratory (BCL) indirectly-heated gasifier, assuming a biomass feedstock price of $2.6/MBTU, a cost target that is expected to be met or beat for biomass grown on dedicated plantations in the US. The costs for coal-derived methanol and hydrogen are for thermochemical gasification of coal using the Shell oxygen-blown gasifier, assuming a coal feedstock price of $2.1/MBTU. The costs for electrolytic hydrogen are based on electricity prices of 5.3 cents/kWh for nuclear power, 4.7 cents/kWh for wind power (currently being achieved), 4.5 cents/kWh for photovoltaic electricity in areas of high insolation (HI, the US Southwest) and 6.1 cents/kWh in areas of moderate insolation (MI, the US average).

FIGURE 15. A COMPARISON OF WEIGHTS FOR MID-SIZED SEDANS[a] BASED ON:

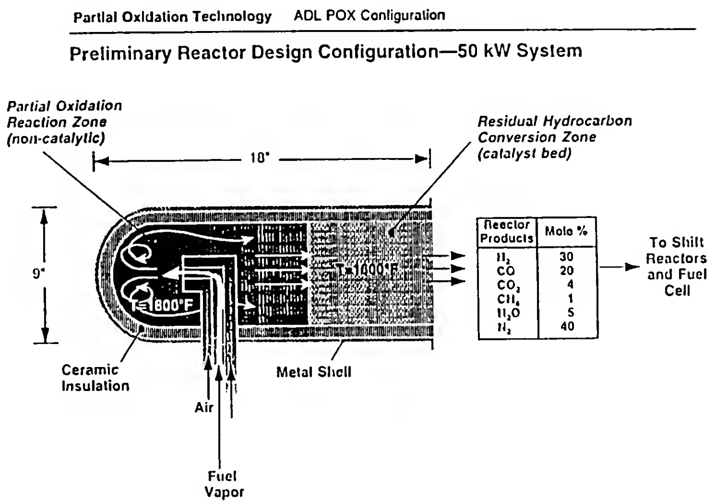
(*i*) weights for an internal combustion engine vehicle *(left)*, and

(*ii*) projected weights *(~ 2004)* for a fuel cell vehicle using compressed gaseous hydrogen storage *(right)*.



[a] Source: James, B. D., G. N. Baum, and I. F. Kuhn, "Technology Development Goals for Automotive Fuel Cell Power Systems," report prepared for the Electrochemical Technology Program, Chemical Technology Division, Argonne National Laboratory, US Department of Energy, February 1994.

FIGURE 16. PRELIMINARY DESIGN OF A DEVICE FOR PARTIAL OXIDATION OF A HYDROCARBON FUEL *(e.g. Gasoline or Diesel)*, FOR PRODUCTION ON-BOARD A VEHICLE OF A HYDROGEN-RICH GAS THAT IS SUITABLE FOR USE IN A FUEL CELL[*]



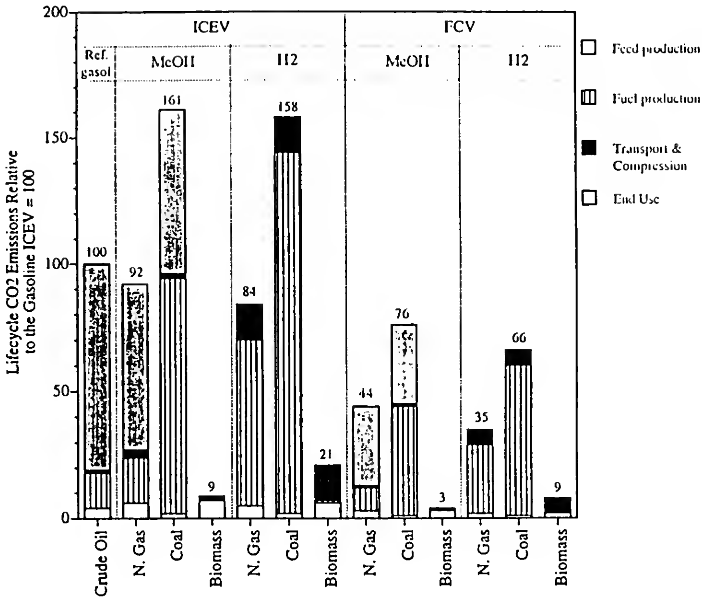
[*] This partial oxidation device for converting a hydrocarbon or alternative liquid fuel into a hydrogen-rich gas suitable for use in fuel cells is under development at A. D. Little, Inc.

The gaseous products produced in the partial oxidation reactor subsequently pass through a water-gas shift reactor, in which the energy contained in the carbon monoxide is "shifted" to hydrogen via reaction with steam:

$$CO + H_2O_{(g)} \dashrightarrow CO_2 + H_2.$$

The output of the shift reactor (a gaseous mixture containing mainly hydrogen, carbon dioxide, nitrogen, and water vapor) is readily useable as fuel by a hydrogen fuel cell.

FIGURE 17. LIFECYCLE CARBON DIOXIDE EMISSIONS PER MILE OF DRIVING FOR ALTERNATIVE ENERGY CARRIERS USED IN ALTERNATIVE VEHICLES[a]



[a] Source: R. Williams, E. Larson, R. Katofsky, and J. Chen, "Methanol and Hydrogen from Biomass for Transportation," paper presented at **Bio-resources '94** *Biomass Resources: a means to sustainable development*, Bangalore, India, 3-7 October 1994.

TABLE 1. Comparison of:
SHELL SUSTAINED GROWTH SCENARIO (SGS)[a]
and
RENEWABLES- INTENSIVE GLOBAL ENERGY SCENARIO (RIGES)[b]
(Prepared as an Input to the
1992 UN Conference on Environment and Development)
(Primary Energy Consumption, in EJ per year)

Energy Supply Source	Actual for 1985	SGS for 2050	RIGES for 2050
Coal	90	188	59
Oil	127	141	64
Natural Gas	65	141	108
Nuclear	15	94	12
Hydro	21	78	32
Intermittent Renewables	-	297	64
Biomass[c]	55	219	206
Geothermal/Ocean	-	31	1
Solar Electrolytic Hydrogen	-	-	33
Surprise	-	31	-
Totals	373	1220	580

[a] Peter Kassler, "Energy for Development," Shell Selected Paper, Shell International Petroleum Company, London, November 1994.

[b] T. B. Johansson, H. Kelly, A. K. N. Reddy, and R. H. Williams, "Renewable Fuels and Electricity for a Growing World Economy: Defining and Achieving the Potential," Chapter 1, pp. 1-71, in ***Renewable Energy: Sources for Fuels and Electricity***, Island Press, Washington DC, 1993.

[c] Includes non-commercial biomass energy, which amounted to 50 EJ per year in 1985. In the RIGES there is no non-commercial biomass energy in 2050.

TABLE 2. US FEDERAL FUNDING FOR ENERGY R&D, TOTAL AND BY CATEGORY[a]
(million 1993 $)

	Total	Fossil Energy	Nuclear Fission	Nuclear Fusion	Energy Conservation	Renewable Energy
1978	8682	1567	4862	681	333	1239
1979	8019	1434	4053	670	412	1451
1980	7725	1439	3770	603	479	1434
1981	7095	1556	3216	617	416	1290
1982	5894	616	3823	665	200	591
1983	5125	308	3565	649	173	431
1984	5369	355	3845	636	185	349
1985	4084	378	2650	562	178	316
1986	3674	394	2388	461	176	256
1987	2951	362	1801	422	151	214
1988	2745	619	1413	394	143	176
1989	2955	643	1612	395	135	170
1990	2279	1047	350	345	196	153
1991	1861	883	236	301	228	213
1992	2109	869	387	339	266	247
1993	1526	414	210	335	311	256
1994	1754	633	99	321	384	317

[a] Source: US Department of Energy, November 1993. Funding was converted to 1993$ by using the GDP deflator.

TABLE 3. ABSOLUTE AND RELATIVE TRENDS IN US FEDERAL ENERGY R&D FUNDING

Year	(1) Energy R&D Funding[a] (10^9 1993 $)	(2) Total R&D Funding[b] (10^9 1993 $)	(3) GDP (10^9 1993 $)	(4) Expenditures on Energy[c] (10^9 1993 $)	(5) = 100* (1)/(2) (%)	(6) = 100* (2)/(3) (%)	(7) = 100* (1)/(3) (%)	(8) = 100* (1)/(4) (%)
1978	8.682	48.90	4573	489.2	17.8	1.07	0.190	1.77
1979	8.019	50.58	4693	560.0	15.9	1.08	0.171	1.43
1980	7.725	50.74	4664	664.0	15.2	1.09	0.166	1.20
1981	7.095	52.29	4744	667.5	13.6	1.10	0.150	1.06
1982	5.894	53.91	4642	626.1	10.9	1.16	0.127	0.94
1983	5.124	57.83	4822	588.8	8.86	1.20	0.106	0.87
1984	5.370	61.94	5126	588.3	8.67	1.21	0.105	0.91
1985	4.083	66.43	5148	555.0	5.99	1.29	0.077	0.72
1986	3.674	69.17	5441	485.9	5.31	1.27	0.068	0.76
1987	2.950	71.51	5607	486.4	4.13	1.28	0.049	0.61
1988	2.745	72.88	5824	484.5	3.77	1.25	0.047	0.57
1989	2.955	71.28	5977	496.3	4.15	1.19	0.049	0.60
1990	2.091	69.68	6045	515.2	3.00	1.16	0.035	0.41
1991	1.862	68.47	6012		2.72	1.14	0.031	
1992	2.110	69.67	6149		3.03	1.13	0.034	
1993	1.526		6343				0.024	

[a] Source: US Department of Energy, November 1993. Funding was converted to 1993$ by using the GDP deflator.

[b] National Science Foundation, "National Patterns of R&D Resources: 1992," NSF 92-330, Washington, DC, October 1992. Funding was converted to 1993$ by using the GDP deflator.

[c] Energy Information Administration, "State Energy Price and Expenditure Report 1990," DOE/EIA-0376(90), US Department of Energy, Washington, DC, September 1992. Expenditures were converted to 1993$ using the GDP deflator.

TABLE 4. TRENDS FOR US INDUSTRIAL ENERGY R&D FUNDING
(billion current $)

Year	(1) Companies' Own Funds[a]	(2) Federal Funding[a]	(3) Total Funding[a] [(1) + (2)]	(4) GDP	(5) Expenditures on Energy[b]	(6) = 100*(3)/(4)	(7) = 100*(3)/(5)
1978	1.796	1.169	2.965	2233	238.877	0.133	1.24
1979	2.230	1.413	3.643	2489	296.992	0.146	1.23
1980	2.599	1.563	4.162	2708	373.901	0.154	1.11
1981	2.680	1.536	4.216	3031	426.447	0.139	0.99
1982	2.762	1.478	4.240	3150	424.809	0.135	1.00
1983	2.842	1.503	4.345	3405	415.749	0.128	1.05
1984	2.962	1.484	4.446	3777	433.462	0.118	1.03
1985	2.537	1.417	3.954	4039	435.443	0.098	0.91
1986	2.167	1.191	3.358	4269	381.257	0.079	0.88
1987	2.410	1.166	3.576	4540	393.843	0.079	0.91
1988	2.353	1.385	3.738	4900	407.602	0.076	0.92
1989	2.271	1.265	3.536	5251	436.009	0.067	0.81
1990	2.687	1.418	4.105	5546	472.657	0.074	0.87
1991	2.691	1.924	4.615	5725		0.081	
1992	2.812	2.077	4.889	6020		0.081	
1993	2.883		5.079	6343		0.080	

[a] National Science Foundation, "Research and Development in Industry," Surveys of Science Resource Series, 1992, 1989, and 1987, Washington DC.

[b] Energy Information Administration, "State Energy Price and Expenditure Report 1990," DOE/EIA-0376(90), US Department of Energy, Washington, DC, September 1992.

TABLE 5. ALTERNATIVE PROJECTIONS OF PV SYSTEM COSTS
(in 1990 dollars)

Parameter	USDOE Interlaboratory White Paper[a]		Williams and Terzian[b]		Zweibel and Luft[c]
	Business-As-Usual	Intensification of RD&D	Business-As-Usual	Accelerated Development	Thin-Film Systems
Installed Capital Cost ($/ kW)					
2000	3820	2540	4470	3610	3190
2005	-	-	3500	2170	1820
2010	2290	1770	2770	1520	910
2020	1530	1250	1850	1060	730
2030	1280	1010	-	-	580
Busbar Cost in 2010 (cents/kWh)					
@ 2400 kWh/m^2/year	7.56	5.88	9.07	5.01	3.89
@ 1800 kWh/m^2/year	10.08	7.84	12.09	6.69	5.19
@ 1200 kWh/m^2/year	15.12	11.76	18.13	10.03	7.79
Busbar Cost in 2020 (cents/kWh)					
@ 2400 kWh/m^2/year	5.10	4.19	6.09	3.53	2.90
@ 1800 kWh/m^2/year	6.80	5.59	8.12	4.71	3.86
@ 1200 kWh/m^2/year	10.20	8.39	12.18	7.07	5.79

[a] Source: INEL (Idaho National Engineering Laboratory), LANL (Los Alamos National Laboratory), ORNL (Oak Ridge National Laboratory), SNL (Sandia National Laboratories), and SERI (Solar Energy Research Institute), ***The Potential of Renewable Energy: an Interlaboratory White Paper***, SERI/TP-260-3674, report prepared for the Office of Policy, Planning, and Analysis, US Department of Energy, Washington, DC, March 1990.

[b] Source: Williams, R. H., and Terzian, G., "A Benefit/Cost Analysis of Accelerated Development of Photovoltaic Technology," PU/CEES Rept. No. 281, October 1993.

[c] Source: Zweibel, K., and W. Luft, "Flat-Plate, Thin-Film Modules/Arrays," National Renewable Energy Laboratory, Golden, CO, November 1993.

Appendix A: Biographical Sketch for Robert H. Williams (January 1995)

Robert H. Williams is a Senior Research Scientist at the Center for Energy and Environmental Studies, Princeton University and head of the Center's Technology Assessment/Energy Policy Analysis group. He was born June 23, 1940. He received a B.S. in Physics from Yale in 1962 and a Ph.D. in theoretical physics at the U. of California, Berkeley in 1967. After four years of basic research in theoretical plasma physics in Boulder, Colorado, he joined the Department of Physics of the U. of Michigan at Ann Arbor as Asst. Professor and shifted his research interests to energy and environmental policy. In 1972 he became Chief Scientist with the Ford Foundation's Energy Policy Project, where he was responsible for the Project's environmental and energy conservation research. He joined Princeton's Center for Energy and Environmental Studies in the fall of 1975.

His research interests include: energy technology assessment; the changing role of basic materials in industrialized societies; energy policy analysis relating to efficient energy use; nuclear energy policy (economics and proliferation); bioenergy; the hydrogen economy; other renewable energy; energy, environment, and development; global energy problems; cogeneration; advanced gas turbines for power generation; fuel cells and alternative fuels for transportation; strategies for separating and sequestering CO_2; the economic costs of reducing green-house gas emissions.

In 1982 he co-organized, with Jose Goldemberg (Brazil), Thomas B. Johansson (Sweden), and Amulya K.N. Reddy (India) the End-Use Oriented Global Energy Project, an effort aimed at identifying and developing long range global energy strategies that are consistent with the solutions of other important global problems with strong links to energy. He co-organized, with Birgit Bodlund (Vattenfall, Sweden) and T.B. Johansson the 1989 International Electricity Congress, sponsored by Vattenfall (the Swedish State Power Board) and aimed at exploring the future prospects for more efficient end-use and new generation technologies and their implications for planning in the electric sector. He is coeditor, with T.B. Johansson, Henry Kelly (Office of Technology Assessment), and A.K.N. Reddy, of the book Renewable Energy: Sources for Fuels and Electricity (Island Press, 1993) that was prepared for the Preparatory Committee for the UN Conference on Environment and Development (UNCED), Brazil, 1992, as input to that Committee's efforts to develop for the UNCED a document recommending worldwide actions to accelerate the development of renewable energy sources.

He is a founding Director of the American Council for an Energy-Efficient Economy and was, until 1989, its Chairman. He is a Fellow of the American Physical Society. In 1988 the Council of the American Physical Society awarded him the Leo Szilard Award for Physics in the Public Interest "for applying physics to end-use energy efficiency and educating physicists, members of Congress, and the general public on energy conservation issues." In 1991 he received the US Department of Energy's Sadi Carnot Award for his work related to energy efficiency. In 1993 he was awarded a 5-year MacArthur Fellowship. He is the 1995 recipient of the Joan Hodges Queneau Palladium Medal of the National Audubon Society and the American Association of Engineering Societies for his work on innovative engineering solutions to environmental problems.

Appendix B: Proposal for a Global Accelerated PV Development Program

Among the renewable energy technologies, photovoltaic (PV) technology is perhaps the most intrinsically attractive but the furthest from being economically interesting for large-scale applications. Yet continuing technological advances (see, for example, Fig. 7) and the modularity of the technology indicate good prospects for making the technology widely competitive at modest cost. The World Energy Council has estimated that the successful launching of a PV industry would require only $5 billion of R&D investment plus $2.5 to $4.0 billion in commercialization incentives worldwide (WEC, 1993)--investments that are modest compared to the public resources that have been committed to the support of nuclear and fossil energy.[1]

It is proposed that a worldwide effort be launched to accelerate the development of PV technology. To illustrate the magnitude of the effort and incentives required, an Accelerated Development scenario that leads to a worldwide level of installed PV capacity of 400 GW by 2020 is described here. Details of the scenario construction are presented elsewhere (Williams and Terzian, 1993).

A useful point of departure for the economic analysis is to note that PV module prices do not evolve as simple functions of time. Price is much better described as a function of cumulative production according to so-called experience curves (bottom graph in Fig. 6). According to such curves, prices fall more quickly the faster the demand growth. Of course, technological constraints could limit the potential for using such curves for predictive purposes. They should be used only in conjunction with predictions derived from the bottom up, on the basis of considerations of prospective technological advances. Predictions of future PV system costs based on the use of the experience curve (Williams and Terzian, 1993) under both Business As Usual (BAU) and Accelerated Development (AD) conditions are not inconsistent with such "bottom up" technological forecasts (see Table 5).

It is assumed that under BAU conditions, installed PV capacity grows at an average rate of 17%/year, 1992-2020 (about the same as for the period 1983-1992--see Fig. 13), so that by 2000 and 2010, cumulative installed capacity would be 1 GW and 6 GW, respectively, and capacity additions would be at rates of 200 MW/year in 2000 and 900 MW/year in 2010. Under these conditions PV systems costs are $4500/kW by 2000 and about $2800/kW by 2010, assuming an experience curve with an 80% progress ratio. Moreover, even by 2020 PV (with 25 GW installed capacity) would account for only 0.3% of world electricity generation. This is not a very interesting future for PV technology.

The AD scenario is defined by growth at an average rate of 29%/year, 1992-2020,[2] so that by 2000 and 2010, cumulative installed capacity is 2 GW and 55 GW, respectively, and capacity additions would be at rates of 800 MW/year in 2000 and 18,000 MW/year in 2010. Under these conditions PV system costs reach

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[1] For comparison (IEA, 1992): energy R&D investments by OECD countries in the period 1980-1991 totaled $77 billion for nuclear fission, $13 billion for nuclear fusion, and $18 billion for fossil fuels. (These sums do not include contributions from France before 1990; French investments have been especially large for nuclear fission R&D.) In this same period, OECD expenditures on PV R&D and all renewable energy R&D totaled $2.8 billion and $10.7 billion, respectively.

In addition, governments often provide subsidies for commercial energy activities. In 1989 the market value of all federal subsidies provided to the energy sector (including subsidies for R&D) in the US amounted to $36 billion, of which $10.6 billion was accounted for by nuclear fission and $21.1 billion by fossil fuels (Koplow, 1993).

[2] For comparison, worldwide capacity for nuclear power in its heyday (1957-1977) grew at an average rate of 37% per year.

\$3600/kW by 2000 and \$1500/kW by 2010, assuming an experience curve with an 80% progress ratio. By 2020 PV (with 400 GW of installed capacity) would account for 4% of world electricity generation.

This AD scenario is ambitious, but its pursuit would probably not cost much and could very well give rise to a high benefit/cost ratio--without taking any credit for environmental benefits--if the targeted applications were in grid-connected, distributed configurations (on commercial and residential building rooftops and at electric utility substations) in areas of the world where there is a good correlation between PV output and the utility peak demand. The market for grid-connected applications is far greater than for stand-alone alone applications, and it is far easier to access. Moreover, PV in distributed grid-connected applications in such regions is far more valuable than PV in central-station, grid-connected applications.

To illustrate the distribution of prospective costs and benefits under Accelerated Development conditions, it is assumed that 1/2 of this market is in the US and 1/2 in developing countries, that ways can be found to get the global community to agree to the projected PV sales path, and that mass purchases are made in auctions by electric utilities according to the agreed schedule. In these auctions the maximum allowable bid price declines each year in accordance with what is expected from projections made using the experience curve.[3] For the US it is assumed that a purchasing utility is given a tax credit equal to the difference between the purchase price of a PV system and its value to the utility. For developing countries it is assumed that the required market subsidies are provided by the governments of the industrialized countries that are the home countries of the PV vendors involved, in exchange for market access via joint ventures between these vendors and local companies in the host developing countries.

The present worth of net future benefits (measured as reduced consumer expenditures on electricity, without taking credit for externalities) is \$90 billion. The present worth of the total cost of the market incentives needed worldwide is \$3.3 billion [consistent with the World Energy Council estimate of the required level of market incentive (WEC, 1993)]. The annualized cost for this market incentive, 1995-2002 (the period until economic breakeven), is \$0.5 billion/year--half for the US installations and half for those in developing countries. It is assumed that the subsidy required for developing countries is provided in equal shares by the US, Japan, and Europe. It is also assumed that public sector support for PV R&D increases to a level 6 times higher than in 1991[4]--so that the extra worldwide public sector support for PV R&D is \$1 billion/year.

The required program cost support from developing countries is zero. The required incremental program support from industrialized countries other that the US is \$0.17 billion/year for incentives for projects in developing countries plus \$0.70 billion/year for R&D (a total of \$0.87 billion/year) over the period 1995-2002 until economic breakeven. For the US, the costs during this period would be \$0.26 billion/year for tax

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[3] In practice the maximum bid price would be periodically adjusted downwards or upwards as a result of real-world technological progess. For the purposes of the scenario discussion, however, cost projections are based on the experience curve.

[4] The "appropriate" level of R&D is difficult to ascertain. The level assumed here is based on an estimate by Richards (1993) that society "underinvests" in PV R&D by a factor of six. A high level of R&D effort is probably necessary to generate the high benefit/cost ratio estimated for the Accelerated Development scenario. It is plausible that performance and cost goals set for PV will not be met by merely refining technologies now on the market or by the companies presently selling PV systems. In light of the low cost of PV R&D in relation to potential benefits of a successful development/commercialization effort, it is probably better to overinvest in R&D, as insurance to reduce to low levels the risk that performance and cost goals won't be met.

credits to US utilities, plus $0.09 billion/year for incentives for projects in developing countries, plus $0.29 billion for increased R&D support (a total of $0.64 billion/year).

It should be possible to find the support needed by eliminating waste from existing government energy programs. For example, in the US the level of support needed is only slightly more than the $0.54 billion/year the government spent in 1992 subsidizing ethanol from grain--a technology with virtually zero prospects of ever becoming competitive. However, if for political reasons such a priority reordering cannot be accomplished, the required level of support could be provided by a carbon tax of $1.3/tC on utility purchases of fossil fuels--a tax that would raise the average price of electricity in the US by 0.34%.

Appendix C: Detailed Comments on the Hydrogen Future Act of 1995 (HR 655)

The bill defines hydrogen too narrowly. While hydrogen is the desired energy carrier at the point of final energy conversion, prior to this point the hydrogen might be transported from the primary energy source and stored until until use as a variety of alternative hydrogen carriers that might be methanol, sponge iron (see Appendix D) or even a hydrocarbon fuel (Fig. 16).

The challenges posed by onboard energy storage requirements that must be overcome to bring about a transition from the internal combustion engine to the hydrogen fuel cell for cars are substantial, but they might well be quite manageable if the shift to the fuel cell and the shift to a new fuel (hydrogen or a hydrogen carrier suitable for the long term) were considered as separable shifts. Initially a shift be made from the internal combustion engine to the fuel cell using a conventional hydrocarbon fuel (gasoline or diesel) coupled to onboard partial oxidation plus water gas shift reactors, and that this initial fuel system remain in place as the dominant fuel system until after research and development efforts have been successful in bringing to commercial readiness an advanced storage system for hydrogen or a suitable hydrogen carrier.

The existence of the partial oxidation of hydrocarbon fuels strategy buys plenty of time for the research community to come up with attractive options for hydrogen or hydrogen carrier storage schemes for the long term.

Page 2, lines 8-9. Water contains hydrogen in a fully oxidized form and thus has zero fuel value. Besides, the production of hydrogen electrolytically from water is an especially expensive way to make hydrogen (Fig. 14). Suggest deleting the words "secures a practically infinite supply from water"

Page 2, line 11: Hydrogen production efficiency is not a serious challenge. The challenge is to find ways to make the overall cost of providing an energy service with hydrogen competitive. This will often require the use of an efficient end-use technology such as a fuel cell.

Page 4, line 1: Hydrogen production via thermochemical gasification of biomass [for the foreseeable future, the least costly way of making hydrogen from a renewable energy sources by a wide margin (Fig. 14)] should be mentioned explicitly. To many, "bioconversion" means production of hydrogen by algae or bacteria--a very long-term possibility, as is also true for photoproduction..

Page 4: line 16: add storage as a liquid fuel plus reforming or steam oxidation near the point of use.

Page 4, line 16: add storage as sponge iron plus steam oxidation near the point of use.

Some funding should be included for integrating production, transmission and distribution, and end-use systems.

Appendix D: On-Board Hydrogen Production via Steam Oxidation of Iron

If the hydrogen fuel cell is to play a major role as an alternative to the internal combustion engine in light-duty vehicle applications, an onboard fuel storage scheme characterized by a high volumetric energy density, an acceptable gravimetric energy density, and a low cost would be desirable.

A potentially low-cost strategy for hydrogen storage characterized by a high volumetric energy density involves use of sponge iron as a hydrogen carrier and its steam-oxidation on-board the vehicle, producing hydrogen and byproduct magnetite (Fe_3O_4):[5]

$$3Fe + 4H_2O_{(g)} \dashrightarrow Fe_3O_4 + 4H_2, \quad \Delta H_R = -149.8 \text{ MJ/kmol of } Fe_3O_4 = -18.58 \text{ MJ/kg of } H_2.$$

Note that for each kg of iron oxidized, some (8*1.008)/(3*55.85) = 0.0481 kg of H_2 (5.78 MJ of H_2 per kg of Fe, for H_2 with a LHV of 0.120 GJ/kg) is produced, along with 1.38 kg of magnetite. This hydrogen storage scheme is being developed by H-Power of Belleville, NJ.

In a previous commercial process, the reaction is carried out at 700 °C. However, as the forward reaction is mildly exothermic, it is thermodynamically favored at low temperatures. H-Power has identified a proprietary catalytst that makes it possible to lower the operating temperature considerably. According to John

[5] The magnetite would be reduced off the vehicle to fresh sponge iron and then recycled. Direct reduction techniques would be used--i.e., reduction would take place at temperatures below the melting point of iron. Today most direct reduction is based on the use of natural gas. Both the CO and the H_2 generated from steam reforming of natural gas are excellent reducing agents. These reducing agents can also be produced by thermochemical gasification of municipal solid waste, other biomass residues, biomass grown on plantations, and coal.

A crude estimate of the efficiency of the overall process of producing hydrogen onboard a vehicle via the intermediate step of reducing Fe_3O_4 to Fe based on commercially available technology is as follows. With best commercial practice, sponge iron is produced from Fe_2O_3 (hematite) using natural gas in the Midrex process at a LHV energy input rate of 9.7 GJ of natural gas plus 110 kWh of electricity, corresponding to a total primary energy input rate of 10.5 GJ (assuming a combined cycle efficiency of 50% for power generation) per tonne of sponge iron product. Assuming an iron concentration of 94% and a metallization rate of 92%, this corresponds to 12.1 GJ per tonne of reduced (metallic) iron. Since 5.78 GJ of H_2 (LHV basis) is produced in steam oxidation of 1 tonne of Fe, the overall efficiency is 100*(5.78/12.1) = 48%. In the future the energy efficiency of the direct reduction process is likely to be improved. Moreover, for iron recycling applications the energy requirements are likely to be less than for making iron out of ore; one difference that would lead to a higher energy efficiency is that since magnetite contains less oxygen per tonne of iron than hematite, less CO_2 would be produced in the reduction process, so that less reactant material would have to be heated to the reactor temperature and less CO_2 quenched afterward.

However, even with current technology, a hydrogen fuel cell vehicle with a gasoline-equivalent fuel economy of 80 mpg would use considerably less primary energy than a 27.5 mpg gasoline internal combustion engine vehicle. Assuming that gasoline is produced from crude oil at 90% efficiency, primary energy requirements per mile for the fuel cell vehicle would be (0.9*27.5)/(0.48*80) = 0.64 times as much as for the internal combustion engine vehicle. Since the carbon content of natural gas is 15.0 kg/GJ, compared to 20.7 kg/GJ for petroleum, the lifecycle CO_2 emissions for the fuel cell vehicle would be (0.64*15.0/20.7) = 0.46 times those for the gasoline internal combustion engine vehicle.

Werth at H-Power (private communication, January 1995): (*i*) on the basis of experiments carried out at H-Power, the catalyst makes it possible to convert 3% per minute of the initial iron in the reactor to hydrogen at a reactor operating temperature of 230 °C, (*ii*) at this conversion rate, the kinetics appear to be acceptable (discussed below), (*iii*) the catalyst is a low-cost material, and (*iv*) the catalyst is easily separated from the spent iron at the time the spent fuel is discharged from the car.

The required iron inventory is determined by the fuel economy and the range. Consider a fuel cell car with a fuel economy of 80 mpg gasoline equivalent [the goal for a radically new car set for the Partnership for a New Generation of Vehicles (PNGV)] and a range of 300 miles between refuelings (the goal specified in the DOE Hydrogen Program Plan). For this car, the storage requirement is 300/80 = 3.75 gallons of gasoline equivalent (@ 0.1206 GJ/gallon) or 0.452 GJ (LHV)--some 3.77 kg of H_2; the corresponding Fe inventory is $[(3*55.85)/(8*1.008)]*3.77 = 78.3$ kg.

The economics are prospectively favorable. The factory-gate price of commercially available sponge iron is $140 per tonne of contained total iron, with 92% metallization, so that the price is $152 per tonne of reduced (metallized) iron. Assuming the sponge iron is transported 100 km to a refueling station (at a cost of $2.25 + 0.021*D per tonne of total product for a distance D, in km, or $5.0 per tonne reduced iron, assuming a 94% iron concentration and 92% metallization) and that the refueling station markup is 10%, the total price to the consumer would be $173 per tonne of reduced iron. The factory-gate price paid for magnetite by producers of direct reduced iron is about $30 per tonne, so that (again assuming 100 km transport to the reduction center) the price paid to the consumer is $26 per tonne of magnetite. Thus the net cost per mile for fuel for a "sponge iron car" is:

$$100*[(0.0783 \text{ tonnes})*(\$173/t) - (1.38*0.0783 \text{ tonnes})*(\$26/t)]/(300 \text{ miles}) = 3.6 \text{ cents/mile.}$$

For comparison, the fuel cost per mile for a 27.5 mpg gasoline internal combustion engine car (with gasoline @ $1.1/gallon) is 4.0 cents per mile. H-Power analysts argue that with "mass-produced direct reduction plants" the cost of sponge iron would be greatly reduced relative to present sponge iron prices.[6]

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[6] To understand the prospects for cost-cutting via mass producing direct reduction plants, consider the iron recycling requirements involved in a large-scale shift to fuel cell cars running on sponge iron. A single car with a gasoline-equivalent fuel economy of 80 mpg driven 10,000 miles/year would require a fuel reprocessing rate of 2.6 tonnes of iron/year. For the entire US light-duty vehicle fleet (for which driving totalled $2.0*10^{12}$ vehicle-miles in 1992), the annual iron reprocessing rate would be 520 million tonnes of sponge iron. For comparison, total primary pig iron production in the US and the world in 1990 totalled 55 and 608 million tonnes, respectively. Thus a shift to the "sponge iron car" would require a major expansion of the direct iron reduction industry, with a shift to operation in the "iron recycling mode." As of 1991 there were only 81 direct reduction plants in the world, and total world production of direct reduced iron was only 20 million tonnes, equivalent to about 3% of world pig iron production. Most capacity is based on the use of natural gas, with more than 80% of the capacity in developing countries.

While conventional blast furnaces have annual capacities of 2.5 - 4.0 million tonnes/year, direct reduction plants are relatively small, with typical capacities of 0.3 to 1.0 million tonnes/year--capacities capable of servicing 120,000 to 380,000 cars/year. As direct reduction technology has the potential of being far cleaner than conventional iron-making (Twidwell, 1980), it is likely that most large towns would have their own iron reprocessing facilities. If the average-sized plant served 100,000 cars (i.e. if the average plant capacity was 260,000 tonnes/year), some 2000 plants would be needed to serve the present US light-duty

H-Power has been investigating this hydrogen storage scheme using commercially available sponge iron pellets (0.3 to 0.6 cm in diameter) having a bulk density of 2000 kg/m^3. (Note that the density of solid iron is 7800 kg/m^3.) H-Power has found that on oxidation the bulk volume of the pellets does not change, so that after oxidation the bulk density of the pellets increases to 1.38*2000 = 2760 kg/m^3. While stoichiometrically the amount of water needed for steam oxidation is the amount produced by the PEM fuel cell:

$$H_2 + 1/2\ O_2 \longrightarrow H_2O_{(l)},\ \Delta H_R = -285.8\ \text{MJ/kmol} = -141.8\ \text{MJ/kg}\ H_2,$$

in the approach being pursued by H-Power, about half the needed water is provided as makeup. (In principle, much less extra water has to be carried. Equilibrium calculations show that about 96% of the water would be reduced to hydrogen at 230 °C; and nearly all of the water would be converted at 100 °C. Of course some extra water must be carried for start-up and for contingencies.)

If a catalyst can be found that would permit effective operation at the operating temperature of a PEM fuel cell, the mass and volume of the reactor and storage container should make only modest contributions to the total system mass and volume. The gravimetric energy density is

$$1.008*8/[(3*55.85)(1 + 1.38)/2 + (4*1.008 + 2*15.99 + 0)/2] = 0.037\ \text{kg}\ H_2\ \text{per kg of system},$$

(neglecting the weight of the container), assuming that 1/2 of the needed water must be carried onboard and assuming that the system weight is the average of the initial and final inventories. If the carried water could be entirely eliminated, the gravimetric energy density would increase modestly to:

$$1.008*8/[(3*55.85)(1 + 1.38)/2] = 0.040\ \text{kg}\ H_2\ \text{per kg of system}.$$

Considering the volume of the system to be the initial volume of the inventories (neglecting the volume of the reactor and storage container walls), the volumetric energy density of the system is:

$$1.008*8/[(3*55.85)/(2000\ \text{kg/m}^3) + (4*1.008 + 2*15.99)/(1000\ \text{kg/m}^3)] = 67\ \text{kg}\ H_2\ \text{per m}^3\ \text{of system}.$$

If the carried water could be entirely eliminated, the volumetric energy density would increase substantially, to

$$1.008*8/[(3*55.85)/(2000\ \text{kg/m}^3)] = 96\ \text{kg}\ H_2\ \text{per m}^3\ \text{of system}.$$

For comparison, the DOE goals for the H_2 program are 0.065 kg H_2 per kg of system and 65 kg H_2 per m^3 of system. Thus there are good prospects for meeting or beating the DOE volumetric energy density goal, but sponge iron would fall short of meeting the DOE gravimetric energy density goal. But as pointed out below, the DOE gravimetric energy density goal seems unnecessarily ambitious.

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vehicle fleet. To bring about such a scale of activity would indeed require "mass production" of direct reduction plants. With mass production of standardized plants, engineering and contingency capital costs could be substantially reduced relative to the situation for plants built on a "one-off" basis.

A Comparison to Fuel Cell Vehicles with Compressed Hydrogen Storage and to Gasoline Internal Combustion Vehicles

Directed Technologies, Inc. (DTI), has carried out a study for the US Dept. of Energy comparing their projections for mass-produced fuel cell cars in the period ~ 2004 with internal combustion engine cars of various sizes (James *et al.*, 1994). The DTI base-case mid-size sedan is a vehicle with a 3300 lb test weight[7] having an acceleration of 0-60 mph in 10 seconds, a 342 mile range, and an 19 mpg fuel economy on the Federal Urban Driving Cycle (FUDC). The fuel cell car with compressed gaseous hydrogen storage would have the same acceleration and range but would have a gasoline-equivalent fuel economy of 50.3 mpg on this hydrogen. (Energy recovery from regenerative braking was not considered in the DTI study.)

Weight comparisons for the gasoline internal combustion engine and fuel cell cars are shown in Figure 15. DTI estimated that if targets for system components are met, the fuel cell energy conversion system would weigh about 28% less than the corresponding energy conversion system for the internal combustion engine vehicle system. However, the hydrogen storage would be bulky. The volume of the stored hydrogen (6.81 kg @ 5000 psi) would be 10.5 cubic feet = 297 liters = 78.5 gallons--some 4.4 times the 18 gallons that would be required for gasoline.

Suppose that sponge iron were deployed instead of compressed hydrogen. At a storage density of 67 kg H_2 per m^3 the storage system for sponge iron would be 101.6 liters = 26.9 gallons--50% greater than for gasoline but just 1/3 the size with compressed gas. At a storage density of 96 kg H_2 per m^3 (i.e., if no extra water has to be carried onboard the vehicle), the required storage volume would be 70.9 liters = 18.7 gallons, the same as for gasoline.

These estimates overestimate the volumetric energy density advantages offered by sponge iron compared to compressed gas. With compressed gas, it is practical to operate the fuel cell at pressure--30 psig is assumed in the DTI analysis for both the fuel and the oxidant. If the fuel cell is operated at atmospheric pressure with the sponge iron system and if the oxidant is not enriched in O_2, the volumetric power density of the fuel cell would be 0.40 times the value at 30 psig, but the total capacity of the fuel cell (in kW) could be reduced 16% because there would be no need for a compressor. It appears that DTI assumes a fuel cell stack power density of 0.88 kW/liter, so that the volume for its 50 kW fuel cell stack is 57 liters, bringing the fuel cell + storage volume to 354 liters for the compressed H_2 system. At atmospheric pressure, some 119 liters would be required for a 42 kW fuel cell stack, so that for the sponge iron case the volume of storage + stack would be 221 liters (some 38% less than with compressed H_2) at a storage density of 67 kg H_2 per m^3 and 190 liters (some 46% less than with compressed gas) at a storage density of 96 kg H_2 per m^3.[8]

On a weight basis, sponge iron storage would not fare as well as compressed H_2 storage. At a storage

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[7] With the use of lightweight materials the weight of "mid-size sedans" of the future could be considerably less than this--thereby reducing the magnitude of the hydrogen storage challenge implied by the DTI assessment. No considerations of such possibilities are taken into account here.

[8] The volumetric power density of the fuel cell for the sponge iron case could be increased by using an oxidant stream that is enriched in oxygen as an alternative to pressurization for increasing the partial pressure of oxygen and thus increasing the power density of the fuel cell. H-Power is developing a proprietary oxygen enrichment technology that would do this.

density of 0.037 kg H_2 per kg of system (excluding the weight of the container), the storage system would weigh 184 kg (405 lb). Assuming the sponge iron reactor plus storage container weighs as much as the gasoline tank (15 kg or 32 lb) the total storage weight for sponge iron would be 199 kg (438 lb). The corresponding weight for the compressed H_2 system is (assuming a half-filled tank) 51 kg (112 lb). For comparison the weight for the gasoline system (assuming a half-filled tank) is 40 kg (88 lb).

For the compressed H_2 case the total weight of fuel storage + fuel cell stack + air compression system is 119 kg (262 lb). Assuming the fuel cell stack for the sponge iron case has a capacity of 42 kW and a power density of 0.44 kW/kg (40% of the 1.1 kW/kg power density assumed by DTI for operation at 30 psig) the weight of the fuel cell stack is 95 kg (209 lb). Adding the storage system weight gives a total weight of 294 kg (647 lb) for fuel cell + storage in the sponge iron case, some 2.5 times the weight for fuel cell + storage + compressor in the compressed gaseous H_2 case.

The total fuel cell energy conversion system weight (fuel system + fuel cell stack + gas management system + burst power augmentation + power balancer and conditioning + motor and gear reduction) for sponge iron is 482 kg (1062 lb), compared to 308 kg (678 lb) for the fuel cell with compressed gaseous H_2, and 409 kg (902 lb) for the gasoline internal combustion engine. The weight penalty of 73 kg (160 lb) compared to gasoline is just 5% of the test weight of the base case internal combustion engine vehicle. This could easily be offset by the use of high strength, light-weight materials in car construction. Thus the DOE target for gravimetric H_2 energy storage density seems unnecessarily ambitious.

In addition to its volumetric storage advantages relative to compressed H_2 storage, the sponge iron option also offers a way to circumvent the public acceptability challenges posed by compressed H_2 storage (the "Hindenburg syndrome").

Heating Needs for Steam Oxidation of Iron System

Note first that some hydrogen would have to be burned to provide heat for water, as the heat provided by the steam oxidation exotherm (18.6 MJ per kg of H_2 generated) plus the sensible heat recovered by cooling the H_2 from 230 °C to the 90 °C operating temperature of the fuel cell (2.0 MJ per kg of H_2) is inadequate. The heat required to evaporate water is 20.4 MJ per kg of produced H_2, and, including the sensible heat required to bring the water temperature to 230 °C, the total heat required amounts to 24.6 MJ per kg of H_2 produced, so that some 4.0 MJ of extra heat per kg of H_2 (equivalent to 3.3% of the heating value of the produced H_2) must be provided from other sources. The extra heat required for the water could be reduced to 2.9 MJ per kg of H_2 (equivalent to 2.4% of the heating value of the produced H_2) if the system were able to operate at 100 °C instead of 230 °C.

In addition, the iron in the reactor must be heated. The iron that must be heated will generally be more than what is oxidized on a particular trip and will be considerably more on short trips. Consider a 15 minute trip of typical driving, in which the average speed is 30 mph. The required average iron oxidation rate is:

$$(0.5 \text{ miles/minute})/(300 \text{ miles})*(78.3 \text{ kg}) = 0.13 \text{ kg per minute},$$

which would require a reactor inventory of 4.4 kg (assuming an oxidation rate of 3% of the inventory per minute), somewhat more than twice the amount of iron that would be consumed on the trip (2.0 kg). Heating 4.4 kg of iron from 20 to 230 °C requires 0.48 MJ, equivalent to some 4.2% of the H_2 energy consumed on this 15 minute trip. (For longer trips the iron heating penalty would be less.) With a system operating at 100

°C the heating penalty for this short trip would be only 0.18 MJ or 1.6% of the H_2 required for the trip.

Thus the total heating penalty with the H-Power catalyst is equivalent to up to 7.5% of the heating value of the hydrogen fuel (reaching this penalty level for short trips). With a system operating at 100 °C, the total heating energy penalty could be kept to 4% of the energy content of the produced hydrogen.[9]

Basic Research Needs

The highest priorities for research are: (*i*) to increase the recovery of water from the fuel cell and thereby reduce the need to carry extra water, and (*ii*) to try to identify low-cost catalysts that make effective operation possible at 100 °C instead of 230 °C. Reducing the amount of extra water that has to be carried would substantially increase the volumetric energy storage density with this scheme. Reducing the operating temperature would reduce both the insulation requirements and the energy penalties associated with operation at 230 °C.

R&D is also needed to improve the overall efficiency of the direct reduction process for recycling sponge iron at appropriate scales using a variety of primary energy supplies (natural gas, biomass, municipal solid waste, etc.) as sources for the reducing agents. As this is an "off-vehicle" activity, identifcation of specific basic research challenges in direct reduction is beyond the scope of this paper.

In principle, other metals could also be used as hydrogen carriers, with onboard hydrogen generation via steam oxidation, but H-Power has surveyed a wide range of possibilities and has found none to be as promising as iron.

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[9] It is not necessary to eliminate all heating requirements. The need to keep the membrane of the PEM fuel cell moist implies that a mixture of hydrogen and water vapor will be used as fuel, so that not all the hydrogen will be consumed on the anode. The hydrogen exhausted from the anode can be burned to provide the needed heating.

Appendix E: The Need for a Long-Term Perspective on Global Warming in Energy Planning

The long-term impacts of the build-up of greenhouse gases in the atmosphere have been given little attention in climatic modeling efforts. The "business-as-usual" emissions scenarios developed in the Intergovern-mental Panel on Climate Change assessments of climatic impacts of greenhouse warming (IPCC 1990; 1992) lead to a quadrupling of the atmospheric concentration of the CO_2-equivalent greenhouse gases relative to pre-industrial levels near the year 2100, but these assessments do not explore the implications of this quadrupling beyond the year 2100. In assessing impacts it is essential to take a long-term view of near-term actions--firstly, because the atmosphere/ocean system will not have fully responded to the increased greenhouse gas concentration level in a hundred years, due to the thermal inertia of the oceans, and secondly, because near-term releases of greenhouse gases are irreversible.

However, in a recent global ocean-atmospheric modeling analysis Manabe and Stouffer (1993; 1994) explore the implications over a 500-year period of a scenario in which the atmospheric concentration of CO_2: (*a*) quadruples in roughly the time frame envisioned for greenhouse gas quadrupling in the IPCC business-as-usual scenario and (*b*) remains constant thereafter.

One of the serious consequences of a quadrupling of the CO_2 concentration found by Manabe and Stouffer is a virtual cessation of the thermohaline circulation, the south-north overturning in the world's oceans, caused by the capping effect of less dense fresh surface water in higher latitudes due to increased precipitation in the warmer, wetter atmosphere. Another is a sharp rise in sea level --1.8 meters just from the thermal expansion of the warmed sea water plus a further large increment due to the melting of continental icesheets (mostly in Greenland and the edge of Antarctica). The latter contribution to sea level rise depends on the extent of refreezing on the icesheets, which is uncertain: with no refreezing, the total sea level rise (thermal expansion plus ice sheet melting) in 500 years would be about 9 meters; if only half of the meltwater eventually reaches the oceans, the total sea level rise would still be about 5 meters; in any case, the prospective sea level rise would be a very serious impact. Further, the 7 °C increase in the global mean air temperature associated with a quadrupling of CO_2 is nearly as large as the inferred difference between today's climate and the very warm Cretaceous period 65-90 million years ago. Although important uncertainties remain and no effort has yet been made to put a dollar value on these prospective global changes, the implications of this modeling exercise, even if only partially correct in predicting the behavior of the ocean-atmosphere system, are daunting.

Such considerations indicate that by far the most important response to the problem of global warming is to find ways to achieve deep reductions in global greenhouse gas emissions relative to present levels over a period of several decades. Fortunately, however, there are good prospects that over the long term deep reductions can be achieved at low cost via an ambitious near-term R&D and commercialization effort focused on improved energy efficiency and renewable energy sources (Johansson *et al.* 1993; Williams, 1994b).

The CHAIRMAN. Thank you, Dr. Williams.

Mr. Brown. Thank you, Mr. Chairman.

May I direct a question to Secretary Ervin.

With regard to the caps which you have expressed your concern about, how serious is this likely to be and are there some alternative language that might be worked out here?

Looking at various scenarios, if you are successful in getting an increased appropriation for energy supply R&D next year, you couldn't spend it if these caps were in effect, as I understand it. If you have a smaller amount in the budget or appropriated, there would be no real effect except you would have to rearrange your priorities within the amount appropriated to accommodate this.

Is there—how do you foresee this playing out, or do you have any way of telling whether you are likely to get a larger or smaller appropriation for energy supply R&D?

Ms. ERVIN. We would certainly like to take some time to see how we could work that out with the provisions of this language.

I think the overriding factor here is that this is such a large portion of our energy budget, $3 billion plus, and it covers such a vast array of various activities ranging from environmental restoration, health and safety, our renewable resource policies, nuclear research and so forth, that it is just very critical that we have flexibility in shaping the relative priorities among those and the amounts that we spend in those categories in response to emerging needs.

So we are certainly very interested in this language, and we would want to work with you on this.

Mr. BROWN. Are you saying your energy supply R&D item is about $3 billion?

Ms. ERVIN. That is right.

Mr. BROWN. This would have a very small impact on $3 billion. The caps would have a major impact.

Ms. ERVIN. The caps would have a major impact, that is right.

Mr. BROWN. All right.

You intrigue my interest with your statement here about the long-range basic research you are doing on photobiological processes. Could you give me some simple indication of how much resources you are putting into that and your evaluation of how promising any breakthroughs might be? Apparently you are also looking at genetically-engineered bacteria and algal systems which might be more efficient in terms of processing solar energy and converting it into hydrogen. These are fascinating problems, and if you don't care to give me any details now, if I could get some later, I would appreciate it.

Ms. ERVIN. Absolutely. They are very promising areas, and I would be happy to provide some detail on exactly what we are doing in those areas for you.

Mr. BROWN. All right. Thank you very much.

May I ask just one further question. Somebody or maybe several of you referred to the fact that hydrogen is inherently a very clean fuel, some implication it is perfectly clean. My understanding is that any combustion process—and which hydrogen would be one—will produce certain NOx emissions or something of that sort. How serious is that problem, Dr. Lloyd?

Mr. LLOYD. I agree with you, Congressman Brown, clearly if you combust hydrogen you do have some NOx, although from our experience they are limited. But even in your own constituency at the University of California, Riverside, you are generating and utilizing hydrogen pollution free. In fact, you can do it if you use the sun electrolysis, and then you utilize it in a fuel cell, hydrogen is truly a zero emission technology.

Mr. BROWN. Yes, well, your mention of that leads me to want to get better acquainted with that program. I thought I knew everything that was going on over there, but obviously I don't, so I'll try and find out more about that.

Mr. LLOYD. Also I realize, I guess, UCR is adjacent to your district, is in Congressman Calvert's.

Mr. BROWN. Well, I forgive you for that minor slip. It has only been two years since I represented it, and I'm sure that Congressman Calvert is equally interested.

Thank you very much.

The CHAIRMAN. Thank you, Mr. Brown.

Mr. Foley. Mr. Foley is no longer here.

Mr. Ehlers.

Mr. EHLERS. Thank you, Mr. Chairman.

I must confess, I am not all that familiar with this field, but I am concerned with some of the language I hear being used, not so much by the panel but in general among the population. We talk about this as being a limitless fuel source when, in fact, hydrogen, as I understand it, is really not going to be a source of energy, it is going to be a—you could use the term "carrier," but it is really an energy storage device where we are going to have to use some mechanism to produce it, and I get very nervous when we talk about zero emissions when we are talking only about the end use and not also including the production mechanism.

Yesterday we had quite a hearing on risk assessment, and one of the key factors in analyzing it is to analyze the entire system, not just the end use.

I am constantly reminded, one of the advantages—there are very few advantages of getting older—well, I guess it's better than the alternative, but one of them is remembering some of the things from the past, such as nuclear energy will be too cheap to meter, and ignoring all the problems that developed, and we chuckle about that now.

I am a little concerned about the rosy scenarios that we hear about hydrogen. It is an extremely difficult material to handle, it is intrinsically very dangerous, and we have a lot of problems to solve in terms of production, storage, and I am also wondering about what side effects there are in terms of pollution generation in the production process. It would be wonderful if you could produce it directly from solar energy, but again the question is, what is the efficiency of that process, what is the cost of that process, how does that compare with the more likely scenarios which might emerge, and that is converting petroleum products into hydrogen, and what are the by-products of that.

As Congressman Brown has pointed out, if you have any sort of combustion, you are going to have other products, and the fuel cell

technology is great, but again what—that implies electric vehicles, I presume, although I am unfamiliar with that.

I am rambling on a bit here, but I just wanted to raise all these concerns and ask for some responses from anyone on the panel who wishes to respond in terms of what is the total picture involved here, and let's recognize, this is purely an energy storage device because you have to produce it somewhere, you have to transport it to the consumer and then use it, unless you develop some nice method of developing it on the vehicle from other raw materials, but I think that is going to be difficult.

Dr. Williams, I see your hand up first.

Mr. WILLIAMS. Yes, that is a very good question, and I would like to address it in the context of what I perceive to be a central thrust of the bill which seems to focus on electrolytic production of hydrogen.

In my opinion, electrolytically-generated hydrogen, whether it is produced from nuclear energy or hydroelectric energy or photovoltaic or wind power, is a relatively long-term possibility for hydrogen. If we make a transition to hydrogen as a major energy carrier, it will be made primarily for a number of decades thermochemically from fuel sources, either fossil fuel sources or from biomass energy sources, not through the photosynthetic—artificial photosynthetic processes and the like that were referred to for Congressman Brown, but by thermochemical gasification using technology that is very similar to coal gasification technology, and in fact initially you were absolutely right, in my opinion if we move to hydrogen for fuel cells initially, a very likely way of doing this is partial oxidation of hydrocarbon fuels, either diesel fuel or gasoline on board the vehicles, and this process will lead to a gaseous mixture of hydrogen and CO2, and the fuel cell will extract the hydrogen from that gaseous fuel mixture.

This is not a zero emission vehicle, but emissions would be dramatically less than they are with using the same fuels in internal combustion engine vehicles, because this partial oxidation process is very clean and you would get significant reductions as well by about two-fifths with regard to CO2 emissions.

When you make hydrogen from coal, you would still reduce the CO2 emissions on a life cycle basis by about one-third relative to a gasoline internal combustion engine vehicle. If you made hydrogen from natural gas, you would reduce CO2 emissions by about two-thirds. If you make hydrogen from biomass and take into account all the fossil fuel needed to grow the biomass and to harvest it and whatnot, you would reduce emissions by more than 90 percent, CO2, and in fact there is a Figure 17 attached to my paper that compares these life cycle greenhouse gas emissions for a wide range of technologies for making hydrogen and also methanol, which is an important hydrogen carrier.

Mr. EHLERS. And what is the overall efficiency of these processes?

The CHAIRMAN. The time of the gentleman has expired.

Mr. WILLIAMS. It varies from one to another. If you—the highest efficiency is to make hydrogen from natural gas, the overall efficiency is about 885 percent if you make hydrogen that way. If you make it from coal and biomass, it will be less than that, but you

get—you offset these losses in energy conversion by the enormous increases in energy efficiency in the end use device. If you have a fuel cell, for example, on a vehicle, a hydrogen fuel cell vehicle is going to be about three times as energy efficient as an internal combustion engine vehicle operating on gasoline, and if you are making hydrogen out of natural gas at 85 percent efficiency you get this enormous net increase in overall efficiency.

The CHAIRMAN. Mr. Doggett.

Mr. DOGGETT. Thank you, Mr. Chairman.

Secretary Ervin, if we place a firm cap on your energy supply R&D and then quadruple the authorization for hydrogen research, what other kind of research is going to have to be sacrificed in order to put more into hydrogen research?

Ms. ERVIN. Well, there could be some serious consequences in a wide array of programs. One of the other aspects of it that would be of concern is that many of the research projects that we have under way are synergistic and indeed complementary to the hydrogen research effort. So if a quadrupling of the funds specifically for this line item did affect our complementary programs in renewables, in biomass for example, as Dr. Williams was referring to, or on the efficiency side in terms of fuel cells, that would indirectly limit the effectiveness of the hydrogen program.

Mr. DOGGETT. Realizing that this is not the first time that Congress has ventured into specifying a particular technology, but really when Congress does that, when it mandates a particular line of research, as this legislation would do, isn't this really just a form of industrial policy where the political decision is being made to elevate one form of technology as a winner over others that aren't favored, that are treated as losers?

Ms. ERVIN. Well, you know, I believe that one of the most important roles of the Federal Government and Congress is to be visionary and to look to the future to estimate what major opportunities exist and major challenges and problems, and so to that extent I think it is indeed appropriate and helpful for Congress to direct and encourage our work in something that has such potential as hydrogen. Technology policy, industrial policy, has many different interpretations and meanings.

If I might elaborate on that for just a minute, I think in my own programs, for example, in renewable and efficiency technologies, we have come a long way in the last 15 or 20 years in the way that we design and implement research and demonstration programs. Twenty years ago when some of the renewable technologies were just emerging, we had 100 percent Federal funding, we had very little industry collaboration and informed industry oversight to our programs. Now it is an entirely different ball game. We have very sophisticated projects and collaborations with industry that help tailor our programs, and that varies considerably depending on where the technology is in the research spectrum.

When you are at the beginning of an emerging technology and there is great risk with potential high payoff, the Federal role of course should be much larger. We can't expect the private sector to do that, especially in this competitive environment that we heard about from other panelists. But as you approach the viability of the technology and the market industry, the Federal role should

diminish considerably, it should be more of a partner and a seeder and a supporter rather than the heavy, heavy investor.

Mr. DOGGETT. So you think Government picking a winner here, a potential winner, is a desirable form of public policy?

Ms. ERVIN. I wouldn't want to use the words "picking a winner," but I would say that I think it is helpful and indeed appropriate for Congress and the Federal Government to provide opportunities to enable such a promising technology as this to flourish.

Mr. DOGGETT. Yesterday in a slightly different context and I guess again on Friday, we will hear a good bit about cost-benefit analysis. Has there been any type of cost-benefit analysis of the merits of engaging in research and development in this type of energy source as contrasted with others?

Ms. ERVIN. Yes. In fact. That relates also to the question previously that we heard on life cycle analysis.

One of the major improvements and enhancements of the hydrogen program, I think, at the Department of Energy has been to undertake systematic what we call pathway analysis, looking at the production of hydrogen and its end use, all the way from the front end of the production to the actual end use, and that includes not only the environmental impacts but also the economic and the technical aspects of that entire pathway. That tool, which is continually being refined, has been very helpful in targeting the technologies that we are focusing on.

Mr. DOGGETT. Since hydrogen has been around about as long as electricity, if it is the superior technology, why hasn't the free market allocated resources here instead of having the Government come in and do it for us?

Ms. ERVIN. May I defer that to another panel member that might have more experience with this?

Mr. DOGGETT. Sure.

Mr. WILLIAMS. Hydrogen is receiving increasing attention today largely because of the environmental constraints that impact the energy system, which are going to be extraordinarily severe as we approach the next century, and as I pointed out, in developing countries this is going to be particularly the case, and it is going to be virtually impossible to beat environmental goals by trying to put bandaids on technologies that we now have that were originally designed with no intention to meet these environmental criteria. Hydrogen offers this potential of being able to meet these environmental goals without these cumbersome control technologies and their associated regulations.

This has not be with us very long. These concerns were certainly not with us at the time that Edison introduced us to electricity, and it has emerged just over the last 20 years, and it is going to be a far more powerful driver in the future.

The CHAIRMAN. The time of the gentleman has expired.

Mr. DOGGETT. Thank you, Mr. Chairman.

The CHAIRMAN. Mr. Doyle.

Mr. TRLICA. Yes, I might add to that that the technology has not been available to us to make cost reductions as far as the fuel cell equation goes when it comes to hydrogen energy. Initially one bipolar plate could cost as much as $5,000 because of the close tolerances required in the machining of it, and are involved—my own

company, in compressed molding, and I can turn out a plate for about a hundred dollars, and we see further reductions. So this is an industry that may be growing on other technologies. We are now able to see the cost reductions that are going to be required to be able to commercialize this.

The CHAIRMAN. Now, Mr. Doyle.

Mr. DOYLE. Thank you, Mr. Chairman.

Secretary Ervin, I would like to do a follow-up to Mr. Doggett's question, under this bill would quadruple expenditures for the hydrogen program at DOE—in your opinion, should this program have the highest priority at DOE over and above other DOE programs?

Ms. ERVIN. I think the way to approach the hydrogen is in the fuller context of the other supporting technologies, and this relates to the earlier answer that I gave.

If we look very narrowly at this hydrogen program line item, that really misses many opportunities to take advantage of work that is going on in dozens of other technologies that are supportive in the biomass and the photovoltaic work, in the efficiency programs, because one of the tools, one of the real keys to accelerating use of hydrogen in this economy in our infrastructure is to accelerate the use of fuel cells both in buildings and in the transportation sector.

Now the key to that is to get the system itself as efficient as possible. When you look at the automobile or the vehicle, for example, the only way that fuel cells are going to be really, really viable is to get the weight down considerably. In the building shell, one of the keys to making fuel cells plentiful and cost effective is to make the building itself very efficient, the technologies in the building, the windows in the shell itself.

So there are so many linkages. We need to have a very clear focus in a hydrogen program, but we need to coordinate that effort with the various other related programs in the Department and another agencies like NASA.

Mr. DOYLE. Thank you very much.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you, Mr. Doyle.

Mr. Luther.

Mr. LUTHER. Thank you, Mr. Chairman. I would like to just follow up on a couple of the questions that have been asked.

We have spent at least one hearing now on risk assessment, and as we talked about risk assessment we talked about the need for agencies to have the best possible information before them when promulgating rules, regulations, whatever, so that they are taking a realistic view of the world. We have listened to that.

What is the best, most objective information we have available on this particular issue as to why we should commit resources and give priority to this particular technology compared to other technologies, obvious obviously if we are going to be focusing on this it means some resources can't go to something else, and I think as decision-makers obviously we want to make sure we are getting the best bang for our buck, if you will.

What analysis has been done? How could that be summarized for us so that we, as we sit here, could make—could feel comfortable

that, based on the best information we have available, we are setting the right priorities here?

Ms. ERVIN. Let me begin to answer that question, and then other panelists certainly may want to jump in.

As I mentioned earlier, the systems analysis work that has been so critical to this program over the last couple of years does include cost-benefit components. It is important to look not only at the economics of it but the technological feasibility and the environmental impacts, and when you take all of those factors into it, is very helpful in helping us focus on particular technologies.

Some of that information is in program plans we will be happy to share with you.

The final thing that I will mention is that the very existence of this Hydrogen Advisory Panel has been very helpful in bringing together and helping synthesize the latest studies that have been done regarding the viability and promise of other technologies, and at that I will leave it to my colleagues here.

Mr. WILLIAMS. I would like to complement those comments by saying that while I am—can truly be characterized as a hydrogen enthusiast, and that is reflected in the fact that I have done an enormous amount of work in this area in the last several years, I also look at the whole energy picture, and there is no silver bullet to solving our energy problems and the challenges that we are going to meet in the—as we move into the 21st century, and, as I pointed out in my testimony, we have a very serious energy R&D crisis across the board in this country and to a lesser extent in other parts of the world; this is true both in the public sector and in the private sector; and if we don't, as a nation, address this we are in very, very serious trouble. And as much as I am a strong supporter of the thrust of this bill, we need to do much more to our energy—to improve our energy R&D situation in this country if we are going to continue having a prospect of substantial economic growth for the long term.

Mr. LLOYD. Can I add to that, one thing; I think we need to put this in context also. We are talking about dollars here. We are talking about relatively minor dollars for hydrogen compared with a lot of other expenditures. So we are not talking about a whole bunch of money, and if we look at the worldwide scene here I think it is imperative, I think, as my fellow panelists have stated, that in order to be competitive we need to be spending those dollars, and also if you look at the environmental and the economic benefits, then I think we are missing a real bet here if we don't, in fact, put additional dollars, plus the fact that, as I mentioned in my testimony, the idea of these clean technologies, you can actually get government out of your hair by, in fact, facilitating the permitting, et cetera, of these technologies.

Mr. LUTHER. If I may follow up, Mr. Chairman, again I would emphasize that I am sure there are many technologies that hold promise and there's a lot of hopes, and obviously we are all very hopeful that we can develop these, but, again, if anyone has information that would show as objectively as possible—and I realize we are in a difficult area—but as objectively as possible how we would benefit from committing resources to this as compared to commit-

ting resources to other areas, it seems to me that would be very helpful to the committee.

And the final follow-up I would have is, what private sector companies are currently working in this area? Where are they located? If whoever has that information.

Ms. ERVIN. I think on both counts let me just follow up with you and provide the information we have, including lists of some of the companies that we are working with.

Mr. LUTHER. Okay.

Ms. ERVIN. The key, the bottom line, though, to your initial question is to have a balanced portfolio of research technologies. If we oversubscribe to one particular technology, we may overreach the technical feasibility of bringing it into market at the expense of other technologies. So the key is balance.

The CHAIRMAN. The time of the gentleman has expired.

Mr. LUTHER. Thank you.

The CHAIRMAN. The gentleman, Mr. Bartlett.

Mr. BARTLETT. Thank you very much.

To put my questions in context, let me indicate that I have a scientific background and so I am familiar with some of the basic technologies here. I also am very supportive of alternative fuels. I personally have photovoltaics, use passive solar, wind machine, have probably too much amp hours, over 3,300 amp hours of storage of the energy. So I wanted to give you that little perspective to put my concerns and questions in context.

By the way, Dr. Williams, I am very pleased—I wish the cameras were rolling when you made your observations that we really desperately need more R&D in alternative energy sources, and I agree with what our bill says, that the Congress finds that fossil fuels are limited. Most people don't act as if they are limited, and I am glad that our bill starts out by saying that.

But then when I read the CRS report, it says—it reminds us that hydrogen cannot be produced directly by digging a mine or drilling a well, and that is certainly true, you don't get it that way, so that it must be extracted chemically from hydrogen-rich materials, and then two of those materials it gives are natural gas and coal, two of the things that we said in the introduction to our bill here are in short supply which is why we need to get on with hydrogen research. Of course the CRS report also indicates that we can get it from water and we can get it from plant matter.

I would like to go back to the reservations that Dr. Ehlers, another—the second scientist in the Congress—indicated, that it really in most instances takes more energy to produce hydrogen than you get out of the hydrogen when you burn it. That doesn't mean that it is not a good idea because it—in the end use, it is quite clean compared to other fuels, and it is transportable, and so forth.

But for those who have questions about the efficacy of hydrogen fuel research, what do we tell them relative to the questions that Dr. Ehlers raised and that I have reiterated and the fact that much of the source of the hydrogen anticipated will come from the fossil fuels whose short supply is the reason we are doing hydrogen research?

Mr. WILLIAMS. First of all, I don't think that running out of energy supplies is ever going to be a serious problem. In the case of

oil, we have an energy security problem in that most of the low-cost oil that is left in the world lies in the Middle East, and so if we continue on the oil binge, what is going to happen is, the rest of the world is going to be increasingly dependent on the Middle East for a long time to come.

We probably have at least as much natural gas in the world as we do oil, and we are only using it at about half the rate that we use oil, and through most of the next century we are still going to be using a lot of oil and natural gas, and in fact we should be increasing our utilization of natural gas relative to the rate at which we use oil, and in the process we can get far more utility out of this natural gas if we were to convert it into hydrogen and to use it in fuel cell vehicles than if we were to use it in internal combustion engine vehicles because, as I mentioned earlier, the efficiency of making hydrogen out of natural gas—that is, the energy content of the hydrogen divided by the energy content of the natural gas, taking into account in evaluating this ratio the energy required to make the hydrogen, that ratio is about 85 percent. In other words, about 15 percent of the energy content of the natural gas is consumed to make the hydrogen. But when you use that hydrogen in a fuel cell vehicle, it will be about three times as fuel efficient as a comparable internal combustion engine vehicle. So that 15 percent lost is dwarfed compared to the big efficiency gain that you get on the other side.

Now if you make hydrogen out of coal, the efficiency of conversion is less, it is on the order of 70, 75 percent, something like that, and if you make it out of biomass it is something less than that, it is on the order of 65 to 70 percent, somewhere in that range, but in all cases you come out way ahead relative to making a conventional fuel such as ethanol or methanol out of biomass and using it in an internal combustion engine vehicle. The gains are system-wide gains, that is the way you should look at it. And if you are going to introduce a fuel such as hydrogen, you are always going to pay more per unit of energy for that fuel than you would with a simple hydrocarbon fuel, you know, in dollars per gallon of gasoline equivalent, and so it doesn't make any sense to me in economic terms to use that hydrogen with conventional technology. You have to really introduce simultaneously technology that is well designed to utilize the unique properties of hydrogen, and one of those technologies which is going to be of paramount importance is the fuel cell that gives you this benefit.

So you can't think of hydrogen just on the production side, you have to think of the entire chain of operations from mining the primary resources through the final utilization, whether it be in a car, or in a home, or in an industrial setting, or what-have-you.

The CHAIRMAN. The time of the gentleman has expired.

Mr. BARTLETT. So in the end use you have two advantages. One is that it does produce less energy—I mean less pollutants, and the second is that it produces energy more efficiently.

Mr. WILLIAMS. Yes. Yes.

The CHAIRMAN. The time of the gentleman has expired.

Mr. BARTLETT. Thank you.

The CHAIRMAN. Ms. Rivers.

Ms. RIVERS. Thank you very much.

I have only one question because this is a new area for me and I'm listening and learning. But one of the issues as I look through the elements of this plan is that there is a requirement for a technical demonstration of a motor vehicle, and I am trying to understand—a motor vehicle using hydrogen. I come from an auto-making area, I have 28,000 auto workers, and my understanding is that the private sector is advancing in the production of a prototype, and are we asking for redundancy here?

Mr. TRLICA. No, I don't believe so. We started, as I stated, the Green Car Project in 1990. It took us three years to bring the car to a state where we could take it out on the road and drive it at a cost of about $4 million. We learned a great deal in that process. We now know that we could do that with much, much less capital investment.

Just to give you an example of what we learned, that automobile, three years, $4 million, the system that we just recently put into an 11-passenger transporter is very similar. We made the decision to start that project the first week in December. We received the vehicle in our facility in West Palm Beach December 23, and then when I left to take the flight up yesterday we were running the vehicle around our facility.

So we have learned so much through the demonstration applications or projects dealing with the Green Car that we now have advanced to that state.

Ms. RIVERS. I am not disputing the efficacy of the research, but my question is whether or not similar research is going on in the private sector on which we can capitalize and not spend additional taxpayer dollars. That is my question. I know Ford is working on it, I know Mazda is working on it, I don't know about some of the other auto makers, and my question is, are we funding an essentially redundant program?

Mr. TRLICA. No, I don't believe so. If I can get my thoughts straight on this, there are many, many advances necessary to bring this to commercialization. There is a proposal that has just been released by the Department of Energy for a low-cost, high-performance fuel cell.

In this particular case, we have teamed with a number of research institutes, and University of Texas A&M being one because of research that is being done there. We will be concentrating not only on increasing the performance for transportation needs but for lighter-weight fuel cells or electrochemical engines.

So there is a lot yet to be done. And I don't believe it is redundant. I could not do this alone. As good as my budget is, I need help, as the case 655.

Ms. RIVERS. So it would be your argument that private industry is not doing the same sort of research that you are doing in this.

Mr. TRLICA. Well, I am private industry. What I am saying is that I can only do so much. I mean the help and the assistance that we get through the program such—and the proposals that are put out by the Department of Energy are very important to us. They help take us to the next plane to be able to commercialize the product.

Ms. RIVERS. Okay.

Ms. ERVIN. I would reinforce that as well. The work that we are doing in our hydrogen program specifically and then in our Office of Transportation Technologies under the Partnership for a New Generation Vehicle is elaborately done in concert with industry. These are partnerships, and we have a carefully designed technology plan that specifies who does what under the development of the fuel cell programs. It is an important part of the hydrogen program in general.

Ms. RIVERS. Okay. Thank you.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you.

Mr. Baker.

Mr. BAKER. Thank you very much, Mr. Chairman.

To answer the gentleman's question, the private firms that are working with Livermore and the CRADA on the hydrogen fuel are Texaco and Lockheed, Lockheed obviously because they want to go to the moon and Texaco because they want to drive around.

We are in a very competitive world. We are in a three-country race for hydrogen fuel with Japan and Germany, and the commercialization, when it occurs, is going to be enormous to the country that wins it. So I would like to suggest to the people on the other side who are worried about Government competing with private sector in research, the real competition is between Germany, Japan, and the United States, and this requires three things:

First, get rid of the antitrust laws so that the companies can work together in America to solve this riddle because the riddle is the fuel cell, not the natural gas or getting the pollutants out, but getting, as Mr. Trlica has said, the fuel cell designed, and I have heard it is as far away as 15 years. So we have got to accelerate how we can get this from beginning to end if we want to be a player in this commercialization.

Secondly, we can stop stealing all the corporations' money so that they will have some more money for research and development, and which includes tax credits or lower corporate taxes if they spend it for R&D.

And third is to stand up to the green scissors Taxpayers Union, every time they see a research project that doesn't have a payoff tomorrow they want to cut it, whether it is hydrogen fuel, NIF, testing of nuclear weapons without actually blowing up the weapons. All of these other research programs are fodder for instant conservatism. The folks that would never cut an entitlement now want to get rid of all science. So we are going to have to form a partnership, we are going to have to have courage to say that creating the next fuel is important.

The last thing. I think we ought to, as government, take an ownership position in some of these CRADA's so that if they succeed, like Chrysler, we will own a small percentage of the stock, not because we want to run the companies but because we want a payback so we can get that money and put it right back out in research again. We are fools for just dishing out money to everybody that thinks they have an idea and then never recouping that.

Lastly, I would like to ask the panel, now that my sermon is over, what do you consider—and the Democratic side have asked this 10 times—what do you consider the prioritization? Is hydrogen

fuel worth fighting for in the commercial sector with Japan and Germany? And Dr. Ehlers gave a glowing dissertation on the shortcomings of every fuel known to humankind. I would like to turn it around and say, what is the prioritization, noting that we are going to need new sources of fuel, and if you hold up Diablo Canyon Nuclear Plant for 13 years of course we are going to have expensive fuel. We could do the same to hydrogen if we are not careful.

Starting with Dr. Williams, why don't we go through and end with Mrs. Irwin, Honorable Irwin.

Mr. WILLIAMS. I would say that I would give the highest priorities for research and development in two areas. One is low temperature fuel cells such as the protonic exchange membrane fuel cell, and second is biomass-based hydrogen production technology based on thermochemical gasification. Those areas I think are key.

And, second, I would like to support and endorse Alan Lloyd's suggestion that we should focus on integrated approaches to realizing hydrogen strategies in which we look—we work through demonstrations and other efforts on entire systems from primary production through end use.

Mr. TRLICA. Well, I have to say that I have been hooked on hydrogen when I first heard the equation water energy water, it just doesn't get any simpler than that, and I think that it makes a lot of sense especially as we see technology advancing with electrolyzers.

Mr. BAKER. How far off are we?

Mr. TRLICA. I think you were right on target. I think it is possible that we can have inner city vehicles, lightweight 4-passenger type cars earlier than that. I think they will be of a nature that would be satisfying to the American public. I believe I can build an electrochemical fuel cell that will be acceptable to the American public for that type of vehicle, inner city transportation, as early as the end of this century. I'm that close.

Mr. BAKER. Good.

Dr. Lloyd.

Mr. LLOYD. Yes, I thoroughly concur with your comments, Congressman Baker. Particularly, I think, on the world sale it is no point us arguing here about relative priorities, and in fact if the rest of the world is playing soccer and we are playing baseball, we are going to lose, and I think that—I know at the end of this week several of us here are going to a conference on hydrogen clean energies in Japan. They are spending money there, so are the Europeans.

We have taken the position in Southern California of following a menu of fuels similar to the Department of Energy, and so I think it is important that that is continued here.

Where do we stand in terms of getting this commercialized? We stand a lot further today as a result of some of the regulations we have had in California, although they may have been popular to satisfying our goals of bringing zero emission technologies out there, including fuel cells. So I think that maybe in the next decade we should be there.

Mr. BAKER. Good.

Ms. Ervin.

Ms. ERVIN. I will conclude by agreeing also that I think that the stakes in the international competition for these technologies and to complementary technologies in renewables are incredibly high. We have a lot at stake here. The various programs and the plans have a portfolio of technologies that are important.

I think the fuel cells are particularly important not only in buildings but in transportation. Japan in particular is betting heavily on fuel cells, and I think the faster that we start—the faster we develop an infrastructure in fuel cells the better off we will be internationally.

Mr. BAKER. Okay.

Thank you very much.

The CHAIRMAN. Thank you, Mr. Baker.

Mr. Roemer.

Mr. ROEMER. Thank you, Mr. Chairman.

Indeed we are here to debate where we want to go with increasingly limited resources and how best to get there, and H.R. 655 may indeed be something that this committee and this Congress decides to emphasize or put more resources into. Certainly the opportunity to ask you all questions about this is precisely what we are going to contemplate and do over the series of hearings and markups that we have in this issue and other issues.

I guess my first question, Secretary, would be to you, and It would involve the requirement in H.R. 655 for over 15 demonstration projects. Does this have industry backing enough to be viewed as industry-led right now? How will industry be involved in the development of the specific demonstrations? And, furthermore, how will the participants be chosen? Is this a good idea to mandate in this bill that we have 15 demonstration projects?

Ms. ERVIN. The general response that I gave earlier to that is that we are supportive of the general direction of the demonstrations and the kind of industry partnerships and the general range of cost share. But we would be very concerned about overprescribing in the details of statutes specifically what kinds of demonstrations we do and when.

As it happens in sections 5(b) and (c), for example, it so happens that we are doing work and demonstrations in a number of these areas, but it is in accordance with the oversight and advice of our Technical Advisory Panel and with the implementation that we have put in place.

Mr. ROEMER. Let me follow up. So with respect to your question and answer from Mr. Doyle, you used terms such as synergy and working together and linkage and coordination. This might be a little bit too much mandating of the minutiae in terms of the 15 demonstration projects specifically allocating percentages of total funding of certain portions of the program. You would agree with that?

Ms. ERVIN. That is right, and that is why we are very eager and willing to work with the committee on the language in this bill. We appreciate the support, we appreciate the general direction, but if we are to have an expert advisory panel and if we are to work in partnership with industry, then we need to have flexible tools to respond to their direction and oversight.

Mr. ROEMER. So flexibility and resilience—

Ms. ERVIN. Flexibility is key.

Mr. ROEMER.—Are what you want.

What about in terms of the money, Secretary Ervin? We are talking about $100 million in terms of the demonstration project with a match of $100 million from industry, and just in terms of demonstrating hydrogen jet fuel engine, aren't we talking about that having the possibility of eating up most of that money?

Ms. ERVIN. Yes, if—

Mr. ROEMER. Are we talking about realistic allocations of resources and money if we are talking about 15 demonstration projects and this jet engine?

Ms. ERVIN. These general amounts that are called for in section 11 are fairly consistent with what would be needed to carry out each and every one of these specific demonstrations, but if there were a cap it would eat into the complementary programs that are indeed very important to the overall hydrogen program. So flexibility again is the key.

Mr. ROEMER. Is there any duplication in what we are trying to do in H.R. 655 with what we are already doing in other departments? The Defense Department, NASA, Department of Transportation are all supporting hydrogen technology development. What is different in H.R. 655 that we are not already doing?

Ms. ERVIN. I think what we would need to do in working with Chairman Walker and members of the committee on the legislation is to make clear how these various or general provisions would be coordinated with other departmental activities. There are a number of specific projects in here that are being carried out in other departments, that is right, so we would need to coordinate very carefully.

Mr. ROEMER. So we would not want to duplicate those efforts with this bill.

Ms. ERVIN. Absolutely.

Mr. ROEMER. Finally, in section 104 of H.R. 655 there is a provision which repeals the Matsunaga Hydrogen Research Development and Demonstration Act of 1990. That Research Act puts a priority on renewable energy.

Ms. ERVIN. That is right.

Mr. ROEMER. How do you feel about the repeal of that section, and does that run a danger of turning this program into a fossil energy based synfuels program? Why, and why not?

Ms. ERVIN. Our position is that we would want to retrain the priority placed on renewable technologies. Certainly fossil fuels are an important transition source, but I think the priority on renewable resources was well placed, and that would be our preference.

Mr. ROEMER. I thank you, and, Mr. Chairman, I would only ask that we have the opportunity to submit additional questions in writing.

The CHAIRMAN. Yes, sir.

Mr. ROEMER. Thank you.

The CHAIRMAN. The panel will be requested to respond to questions that might come from the committee in writing since we do operate with limited time.

[No additional questions submitted]

The CHAIRMAN. I want to thank the members for their good questions; it has helped us, I think; and the panel for your responses.

Let me first of all comment on a couple of things that have been said in the course of both the questions and the commentary which I think represent some misreadings of the bill.

First of all, it seems to me that the need to prioritize this research stems from a number of things that the panel has said to us but also stems from the fact that we need to, as a nation, if we are going to save the costs associated with many aspects of inefficiencies in our society, need to begin doing research that has a dual purpose to it, or maybe larger than a dual purpose, and that the advantage in this particular instance is that it allows us to look at both our energy problems and our environmental problems in one research stream, and that is attractive to me.

It seems to me one reason for prioritizing this kind of research is where you get a dual purpose, and ultimately if you can end up by having more efficiency in your economy because you are able to eliminate a lot of regulation because you have created clean energy sources, that reduces costs enormously across a whole stem.

Now I realize that there are people who are kind of into the power equation and they like the idea of Government doing regulation because it increases Government power. I personally think the dispersal of power is in our long-term best interest and that those kinds of efficiencies in society will, in fact, make us more globally competitive, so that if we want to know a reason for prioritization of this kind of research it seems to me because you get a couple of different advantages from it.

Secondly, there are those who have suggested that somehow we are developing some narrow stream of research here. I don't believe that anybody who has actually read the bill can say that that is the case. It is clear that the bill is aimed at doing basic science. It says so in several places in the bill. We are not attempting to develop a stream of research here which goes to demanding of industries that they move in particular directions. In fact, I am sensitive to the fact that some people seem to think that we are overprescribing, and we may have to come back with the chairman's mark on the bill that takes away that prescription, and I am very sensitive to what you have said, Secretary Ervin, in that regard and will certainly work with you to see whether or not some of the percentages that we have in there for research or some of the particular demands that we have for technical demonstrations go too far.

In my view, all we were asking was that after the basic research is done the Department ought to have the discretion to go to a technical demonstration to see to it whether or not the basic research has, in fact, produced something of value. I mean that was the reason why we were doing that. If, in fact, that is too prescriptive, we are certainly willing to back away from that. It is not our intent to bind the Department in a particular way.

There was a mention here a few minutes ago about matches and their being mandated. Again, any reading of the bill—there are no matches with industry mandated. It was, in fact, the intent of the bill to assure that when we move toward feasibility kinds of studies that the industry be involved but it was waiverable on the part of the Secretary if that is not practical. So there is no such mandate.

It seems to me that one of the main problems we have is over this issue of the cap, and, again, we are willing to work with that, and I have indicated to Mr. Brown that we are willing to work with him. But let me explain my reasoning, and then I want to ask a couple of questions relative to it.

We are not going to be able to get this program through the Congress if in fact what it appears as is add-on spending. I realize every Department comes in here, and if somebody has a new idea and so on, they like to think that they can get some add-on resources as a result of the development of that priority. That is not going to happen in this Congress, and in fact it will destroy our ability to prioritize this program if that is in fact the case.

So what we want to do is assure that there are no additional costs to the taxpayer involved in the program, that what we are doing is prioritizing this time of research but we are doing it within the context of spending limits.

If there is some better way of achieving that end so that we can provide that kind of assurance to the Congress, I am perfectly willing to look at language that does that without imposing a cap on the entire account. In all honesty, as we have looked at it, we don't see a way other than that to get to it, but we are willing to work with anyone, because the intent here is to provide an assurance that this is not going to be add-on spending but it is reprioritization of spending, and I might make a comment in that regard to some who have suggested that we are quadrupling the research here so therefore we are making this the single highest priority within your Department.

I think that anybody who goes back and looks at the figures will understand that that is not the case, but it is a problem that we have had for some years. We fought for a long time, for instance, to get a line item for hydrogen in the appropriation bill, and in all honesty we fought some of your predecessors, Secretary Ervin, at your Department in order to get that done, because this has not been something where there has been much priority in the past, and what we are attempting to do is to say that we think it should have a higher priority than it has had in the past, but in terms of the overall spending in other energy categories we would still have a fairly modest sum of money being authorized under this program, but it is important that it be done within some sort of a cap level, and I think that is what we are trying to do.

Let me ask you. I want to come back to a question Mr. Brown asked earlier. Do you expect that the 1995 level that is included in the cap is in fact going to be a limiting kind of cap in any kind of budget scenario that you see emerging in the next few days or few years?

Ms. ERVIN. I would have to get back to you on that. I think our major concern, and let me say immediately that your words are very welcome indeed and I think we will be very happy to work with you given the outlines that you have provided, but we should get back to you very shortly on that, obviously in the next couple of days.

The CHAIRMAN. Probably by the 6th or the 7th, right?

Ms. ERVIN. Probably by the 6th, that is right.

[Laughter.]

The CHAIRMAN. Well, the reason for using the 1995 cap is because, in all honesty, my guess is that that is probably the high water mark of where that budget is going to be based upon whatever rumors I have been able to pick up, and so it was not designed to limit you in any way, but it was designed to give a level of assurance that at no time were we going to exceed 1995 appropriations in this area. If in fact that proves to be a limitation that would create irresponsible kinds of problems in your allocations, we want to avoid that. We are going to figure out a way to make this thing workable but yet achieve the goals.

Ms. ERVIN. Thank you very much.

The CHAIRMAN. So if we can in fact work with you in that regard, that would be most helpful.

Ms. ERVIN. Absolutely.

The CHAIRMAN. With regard to the Matsunaga Act and the repealing of sections 104 and 105, again, our intent was not to move away from renewables, but we were getting to exactly the problem that some others have identified here earlier today, and that is the question of prescribing the research.

In fact, what the Matsunaga Act did was prescribe research largely to be oriented toward renewables. We are suggesting that there are a number of areas of basic science within hydrogen that ought to move beyond that fairly narrow category, and we thought we were giving a broader prescription, and thereby repealing those sections simply gives the Department more discretion in terms of allocating its research.

Now given that as a parameter, is that a real problem in what we have done here, and is there some language that we can develop that would assure that renewables remain a part of your agenda but simply are not the only thing driving the hydrogen program?

Ms. ERVIN. Well, I'm certain that we could find some language that supports your intent there that we would be very agreeable to.

The CHAIRMAN. Okay. That is fine.

One final question, and then we have had Mr. Geren come in, and I want to give him a chance to ask some questions too.

Do we believe that other countries who are aggressively pursuing hydrogen research at the present time are in fact ahead of us, behind us, in the same kind of ball park that we are in, in their progress toward making hydrogen into a realistic commercial fuel? Dr. Lloyd.

Mr. LLOYD. I think Dr. Williams has probably reviewed this field more than I have. I would like to say that within the next week, after going to the international conference in Japan, I will be happy to provide you with a written answer to that.

The CHAIRMAN. Good. That would be most helpful.

Dr. Williams.

Mr. WILLIAMS. I think that in some areas we are ahead; in others, others are ahead. For example, Germany has perhaps the most continuous and persistent program in hydrogen, but on the other hand many of the breakthroughs in things like PEM fuel cells are coming from North America, both from the United States and Canada. So it is very difficult at this time to say who is ahead in this

race. There is plenty of room for everyone in here, and—but we are not losing.

The CHAIRMAN. But I think that is helpful to understand. In other words, if we put additional resources in it, there is a chance that in fact we can make some significant advances that will give us a chance of being a leader in this kind of technology. Is that correct?

Mr. WILLIAMS. That is correct, and I think what we ought to be doing here is playing to our strengths and our opportunities, and I would like to come back to, in that regard, tie in a couple of points that you made here together, and one was your first comment on dual purpose technologies, and you highlighted this nexus between clean environment and energy which is especially important, but there are a number of other extraordinarily important dual and multiple purposes that ought to be exploited, and I want to put in into context a little bit what I mentioned about biomass.

I mean not only is it going to be by far the cheapest way of making hydrogen from renewable energy sources, but also you have a very significant opportunity in the biomass area, by pursuing biomass energy strategies, of providing a very attractive mechanism for ultimately phasing out agricultural subsidies because at the present time we pay the farmers not to grow food crops to prop up the food prices.

The CHAIRMAN. Wait till I tell Dick Armey about this.

[Laughter.]

Mr. WILLIAMS. And this is really a pretty crazy strategy, and what we ought to be doing is, instead, encouraging farmers to grow energy crops on this excess agricultural land, and the prospects are very good at least in two areas for doing this competitively. You are not going to do it competitively by making ethanol from grain, which always requires very substantial subsidies and I think it has no economic future whatsoever. I will just flatly and categorically say that.

But on the other hand, if you make electricity from biomass using advanced integrated gasification combined cycles, and subsequently if you make hydrogen or methanol out of—which is a hydrogen carrier—out of biomass by means of thermochemical gasification techniques, you have got very good prospects of those technologies being competitive without the necessity of any agricultural subsidies whatsoever.

In other words, the farmer could get the income which he has come to expect with the subsidy programs if he is serving these energy markets with these advanced conversion technologies for making electricity and later methanol and hydrogen, and so you have this very significant dual purpose which will also provide you with, in the longer term, as you phase out these subsidies, with continuing support for the overall effort.

The CHAIRMAN. I thank you very much for that, because I come back to my point that there are some new technological options that in fact give us an opportunity as a society to get greater efficiencies and at the same time expand our economic opportunities, and if in fact we are able to do those kinds of things, it seems to me that that should begin to prioritize where Government puts its research dollars.

Mr. Trlica.

Mr. TRLICA. Yes, I would like to comment also, and I agree with Dr. Williams that we are about neck and neck with Germany and Italy. But in response to your comments about additional R&D and what it could do for us, I believe very strongly that we are at that crossroads now, that we need to concentrate on these side or fringe technologies. Whereas I believe we are equal in size and performance as far as fuel cells go with other countries, I think we are a little ahead in cost reduction.

I think that my particular company has made some serious moves in reducing the cost of PEM fuel cells. We have the possibility of reducing that in multitudes of factors with such things as an oxygen enhancement filtration system that would literally pull out some of the nitrogen out of the ambient air, giving us higher performance on air operation.

We are also working on an automated M&E device where we would be able to use laser printers to literally make our M&E's for us, something which now we do by hand and it is very time consuming and very costly. Here again, I think that would reduce the cost of the M&E's by at least a factor of 10.

So the R&D is very critical right now, and it can give us that edge that can move us miles ahead of the rest of the world.

The CHAIRMAN. Thank you very much.

Mr. Geren, do you have any questions?

Mr. GEREN. Thank you, Mr. Chairman. I have a couple of quick ones.

The bill finds that—let me quote from the bill—"basic scientific fundamentals are needed," close quote, to develop, quote, "new and better energy sources and enabling technologies," close quote. If significant basic research is still required, can the program reach the goal of demonstrating technical feasibility, much less economic viability, in a period as short as the next five years?

Secretary, you might speak to that.

Ms. ERVIN. If I might, I would defer this to my esteemed scientists on the panel. I will give you a short prelude though before they respond, and that is, one of the dramatic changes in the hydrogen program with the Department of Energy has been broadening the portfolio to include near and short term.

Industry told us, university advisors told us, that in order to accelerate the widespread use of hydrogen we need to have near and midterm successes as well while keeping our eye on the longer-term basic science that is needed. And with that, I will leave it to you.

Mr. LLOYD. Yes. Before Dr. Williams answers maybe on the more technical side, I would like to emphasize a comment I made in my testimony, and that is, if we are to do anything in the near term, I think you seriously have to look at the procurement process of the Federal Government.

We are a small bureaucracy out in Southern California, and it takes time to get contracts through, but I am sure my colleagues at DEO are equally frustrated with the time it takes to get paperwork through their agency, and I think that in terms of getting anything short-term done, you can chew up half the time of a five-year time program before any money flows, and so I think that is

an important issue that should be addressed if we are talking about streamlining government, getting dollars to where they can actually pay off to improve the technology.

Mr. GEREN. You might consider setting a 100-days program in place perhaps, Mr. Chairman. You can get a lot more done in 100 days than you realize.

[Laughter.]

The CHAIRMAN. If the gentleman will offer that amendment when we mark up, we may take that into it.

Mr. GEREN. I don't think my constitution can handle it. This is the only hundred days I want to do this lifetime.

Mr. LLOYD. Well, again, I certainly—coming from California, I think people here, far better than I do, understand what needs to be done to facilitate that, but that shouldn't be overlooked.

I don't know whether Dr. Williams has some of the technical issues to raise.

Mr. WILLIAMS. I guess I would just like to make one point that if you want to accelerate the rate of moving to a hydrogen economy, it is going to be very important to broaden the definition of what we usually consider as hydrogen, and much of the traditional thrust has been focused on hydrogen production somewhere at a centralized facility on the ground and that is being transported to the—through the distribution system and ultimately to the user where he would use the hydrogen.

But you can make hydrogen in a hydrogen economy at any point, right up to the point of final use, and, as I pointed out in my earlier comments here, a very effective way of launching a hydrogen economy in the transport sector may well turn out to be using existing hydrocarbon fuels and the infrastructure that is already there and convert those hydrocarbon fuels into hydrogen on board the vehicle by the process that is called partial oxidation that a number of firms are looking at, and you have in the case of hydrogen a very serious problem of a chicken and egg: How do you get the whole thing going?

There is a big change in infrastructure that is required in lots of different areas, and you want to sort of solve one problem at a time if you want to move this along quickly, and one way of moving this along quickly is to try to find ways to use the infrastructure that you have for conventional fuels, and so if you include partial oxidation of hydrocarbon fuels under the rubric of hydrogen, you are making a big step forward to getting this ball rolling in the near term.

Mr. GEREN. Thank you.

A question for the Secretary.

How have funds been awarded in the past in the hydrogen program? Have they been—have there been open competitions, or have the funds been awarded to unsolicited proposals?

Ms. ERVIN. A combination. It really depends. The Department in general relies heavily on competitive solicitations, but if the research is very special, if it is unique, if we are dependent upon the unique infrastructure at a particular research facility, if we receive a really outstanding unsolicited proposal, then we would take that into consideration, and then the various proposals for hydrogen, we have a combination of all of those.

As the program progresses and as the technology is developing, we will be moving more and more toward competitive solicitations wherever possible.

Mr. GEREN. Could you give a rough breakdown, either in number of awards or dollar amounts of awards, about how things have gone in the past?

Ms. ERVIN. I would be happy to provide more detail on that to you within the next couple of days.

Mr. GEREN. All right. Thank you.

I have no other questions, Mr. Chairman.

[The information follows:]

(Shoot all) Harlan

The Secretary of Energy
Washington, DC 20585

March 21, 1995

RECEIVED

MAR 2 2 1995

Committee on Science

The Honorable Robert S. Walker
Chairman, Committee on Science
U.S. House of Representatives
Washington, DC 20515

Dear Mr. Chairman:

This letter contains information on unsolicited proposals funded in support of hydrogen research promised in our interim response dated January 31, 1995.

As indicated in our original response, the Department of Energy relies primarily upon competitive solicitations to accomplish program objectives. However, we also use the unsolicited proposal process, especially to support research that is unique and innovative, demonstrates a unique capability, offers a service not otherwise available to the Government, and does not resemble a pending competitive action. All unsolicted proposals are reviewed and awarded or denied in accordance with Federal law, including Title 48 Code of Federal Regulations (CFR), Chapters 1 and 9 and Title 10 CFR Part 600 Financial Assistance Award, which govern the acceptance and funding of proposals.

In response to your request for information on the Department's hydrogen research and development activities, we are enclosing a summary of the competitive contracts awarded that comply with the Energy Policy Act of 1992, and a summary of funded unsolicited proposals and the rationale for their selection.

If we can be of additional assistance, please contact me or have your staff contact Mr. William J. Taylor, III, Assistant Secretary for Congressional and Intergovernmental Affairs (202) 586-5450.

Sincerely,

Hazel R. O'Leary

Hazel R. O'Leary

Enclosure

cc: The Honorable George E. Brown, Jr.
Ranking Minority Member

Energy Policy Act, P.L 102-486
Section 2026 RENEWABLE HYDROGEN ENERGY
Competitive Contracts

Pursuant to the Energy Policy Act of 1992, the following contracts have been issued/awarded.

"(1) at least one program to generate hydrogen from renewable energy sources;"

Contract: Renewable Energy Fuels and Electricity from
Renewable Resources
Princeton University
Contract Number: XR-11265-1
Contract Amount: $100,000

"(2) at least one program to assess the feasibility of existing natural gas pipelines carrying hydrogen gas, including experimentation if needed, with a goal of determining those components of the natural gas distribution system that would have to be modified to carry -
(A) more than 20 percent hydrogen mixed with natural gas; and
(B) pure hydrogen gas;"

Contract: Assessment of the Feasibility of Using Hydrogen Blends and Pure Hydrogen in Existing Natural Gas Pipelines
Princeton University
Contract Number: XR-11265-2
Contract Amount: $130,000

"(3) at least one program to develop a hydrogen storage system suitable for electric motor vehicles powered by fuel cells, with emphasis on -
(A) improved metal hydride hydrogen storage;
(B) activated carbon-based hydrogen storage;
(C) high pressure compressed hydrogen; or
(D) other novel hydrogen storage techniques;"

Contracts: (1) High Efficiency Stationary H_2 Storage
A.D. Little
Contract Number: ZAR-4-13294-03
Contract Amount: $286,869

(2) Proposal to Develop Improved Metal Hydride Technology for the Storage of H_2
Energy Conversion Devices, Inc.
Contract Number: ZAR-4-13294091
Contract Amount: $659,234

(3) Iron-H_2 Storage System R&D
H-Power
Contract Number: ZAR-4-13294-02
Contract Amount: $83,807

"(4) at least one program to develop a fuel cell to power an electric motor vehicle;"

Contracts: (1) Proton Exchange Membrane (PEM) Fuel Cell System for Light Duty Vehicles
General Motors Corporation
Contract Number: DE-CH02-90CH10435
Contract Amount: $44,922,000

(2) Direct-Hydrogen-Fueled (PEM) Fuel Cell System for Transportation Applications
Penstar Electronics Inc. (PEI) (A Chrysler Corporation)
Contract Number: DE-AC02-94CH50390
Contract Amount: $14,990,062

(3) Direct-Hydrogen-Fueled (PEM) Fuel Cell System for Transportation Applications
Ford Research Laboratory
Contract Number: DE-AC02-94CH50389
Contract Amount: $13,803,279

(4) Phosphoric Acid Fuel Cell/Battery Power Source Integrated in a Test-Bed Bus
H-Power Corporation
Contract Number: DE-AC02-91CH10447
Contract Amount: $15,855,000

(5) Fuel Cell Locomotive
Solicitation will go out the first week of February 1995

(6) Program Research and Development Announcement (PRDA) for Advanced Fuel Cells for Transportation Applications
Solicitation went out January 6, 1995
Contract Number: DE-RA08-95CE50384

(7) Multifuel Reformers for Fuel Cells and Assessment of Hydrogen Storage Technologies
A.D. Little, Inc.
Contract Number: DE-AC02-92CE50343
Contract Amount: $3,536,298

Unsolicited Proposals in Hydrogen Production R&D, fiscal year 1995

(1) Jet Propulsion Laboratory **(Interagency Agreement in Place)**
"Modeling Biomass Pyrolysis for Hydrogen Production"

Description: The purpose of this interagency agreement is to develop a model to describe a biomass vortex reactor in which low-temperature pyrolysis transforms biomass into an oil-vapor and char residue as a precursor to hydrogen fuel. This a collaboration between JPL and the National Renewable Energy Laboratory (NREL) where NREL will provide experimental data and JPL will provide a computer model. This activity is new in fiscal year 1995.

Justification: Under previous DOE sponsorship, JPL has developed unique models of porous particle gasification and burning. These JPL capabilities, not available elsewhere, are directly related to the proposed biomass modeling effort.

(2) Air Products and Chemicals, Inc. **(cooperative agreement pending)**
"Sorption Enhanced Reaction (SER) Process for Production of Hydrogen"

Description: Under this cooperative agreement, Air Products and Chemicals (APC) will develop an approach for producing hydrogen through Sorbant Enhanced Reforming. This is an innovative production method that significantly reduces the capital cost, emissions and improves the efficiency of the process. This cooperative agreement meets all of the criteria specified in Title 48 Code of Federal Regulations. This activity is new in fiscal year 1995.

Justification: All anticipated facility needs for the SER development are available within its Corporate Headquarters complex near Allentown, Pennsylvania. In particular, APC is unique in that they have a fully operational bench-scale laboratory unit which is capable of testing the SER concept under various conditions of temperature, pressure, and gas flow rates. APC has made a corporate commitment to install the process in their production plants after the development phase.

(3) Solar Reactor Technologies, Inc. **(cooperative agreement in place)**
"Solar Photochemical Production of HBr (hydrogen bromide) from Bromine and Steam for Off-Peak Electrolytic Hydrogen Production"

Description: Under this cooperative agreement, Solar Reactor Technologies (SRT) will develop an approach for producing hydrogen electrolytically using a reversible fuel cell and solar-generated HBr. The enabling technology for this system is an efficient, reversible H_2-Br_2 fuel cell, well-suited for utility load-leveling. The net result of the process is the production of hydrogen and oxygen from solar energy, water, and off-peak electrical power from the utility grid. This concept has been patented by SRT (patent 5,219,671). SRT has unique capabilities to perform the project because of extensive previous experience in related research. This activity is new in fiscal year 1995.

Justification: This proposal was funded because of the unique, innovative concept to produce hydrogen from renewable energy resources which was patented by SRT. This proposal meets all of the criteria specified in Title 48 Code of Federal Regulations.

(4) Florida Solar Energy Center **(new grant)**
"Sustainable Hydrogen Production"

Description: Under this grant, researchers at Florida Solar Energy Center (FSEC) will perform a three-year multitask experimental and theoretical activity to develop a comprehensive understanding of the processes involved in solar photocatalytic production, development of solid electrolytes, and thermocatalytic cracking of natural gas.

Justification: These unique methods to produce cost-competitive hydrogen without the release of greenhouse gases, carbon dioxide and carbon monoxide. FSEC will provide improved understanding of the process and develop technologies that can be transferred to industrial partners for commercialization.

The proposed work represents a followon to the activities carried out under NREL contract XD-0-10090-11. FSEC has already developed many of the research tools required to obtain the necessary experimental data. The Department has invested over $694,000 over a three-year period to support research at FSEC. If the award was not made to FSEC, another research organization would require the additional time and funding which would be an unnecessary burden to the government.

(5) Princeton University **(new grant)**
"Hydrogen Energy Systems Studies"

Description: Under this grant, researchers at Princeton University are to develop a comprehensive understanding of the processes involved in small scale production of hydrogen from natural gas and research in development of hydrogen energy markets in Southern California.

Justification: The proposed work represents a follow-on to the activities carried out under an NREL contract, XR-11265-2. Princeton has unique capabilities to assess the energy infrastructure needs of the program which were developed under prior DOE contracts in the biomass field. The Government has invested over $230,000 to support research at Princeton. The present contract, involves the assessment of the natural gas infrastructure to meet the requirements of EPAct Section 2026 sections 2(A) and (B). This work is leading the effort to perform technical and economic assessments of hydrogen energy systems. This institute was highly recommended by the Hydrogen Technical Advisory Panel.

(6) University of Hawaii at Manoa **(new grant)**
"Hydrogen from Renewable Resources"

Description: Under this grant, University of Hawaii at Manoa, Hawaii Natural

Energy Institute (HNEI) will conduct advanced research in the areas of direct photoconversion, biomass growth, harvesting, and conversion, and lightweight compact hydrogen storage. This research is a continuation of work performed by HNEI under NREL contract XAR-3-13514-01 under which HNEI has provided data on: (I) advanced storage materials, polyhydride complexes, metal-inorganic complexes exhibiting the potential to store large quantities of molecular hydrogen; (2) the molecular basis of biological hydrogen metabolism and evolution; (3) photoelectro-chemistry using wide bandgap semiconductor materials; and (4) thermochemical production of hydrogen from wet biomass. Each of the senior researchers has developed laboratories equipped with a variety of equipment specifically designed for the development of hydrogen technologies.

Justification: The Department has invested over $535,000 to support research at HNEI. This work is at the leading edge of technology for advanced storage and production. If not awarded to Hawaii, another research organizations would require a minimum of $450,000 and two years to establish the capabilities already in place at the University of Hawaii, which would be an unnecessary cost to the Government.

(7) University of Miami (grant pending)
"Solar Hydrogen Energy System"

Description: Under this proposed grant, the University of Miami will conduct investigations of the use of photovoltaics to produce hydrogen, a fluid-flow and heat & mass transfer investigation of Proton Exchange Membrane fuel cell stacks, and hydrogen safety studies.

Justification: This work represents a followon to the activities carried out under an NREL contract, XD-0-10087-1. The Government has invested over $250,000 to support R&D at the University of Miami. Miami leads all of the work defining the safety aspects (codes and standards) for hydrogen technologies under development. Miami has unique capabilities that have been developed under previous DOE contracts to conduct research and development on renewable energy sources and safety analysis.

The CHAIRMAN. Thank you, Mr. Geren.

Any other questions from any other members?

Mr. Ehlers.

Mr. EHLERS. Just a very brief comment. I always measure the value of a hearing by the amount I have learned from the panel, and on that basis this has been a very good hearing and a good panel. I congratulate you and thank the panel.

The CHAIRMAN. Thank you.

Let me also thank the panel. I think this has been very useful. It has been helpful to us in terms of development. All of you have indicated a willingness to work with us. I assure you, we will want to do that over the next few days. We are going to try to move this bill to markup in the relatively near future and look forward to working with you as we try to develop some things that this hearing, I think, has told us probably should be modified somewhat in the original bill. So thank you very much.

With that, this hearing is adjourned.

[Whereupon, at 10:53 a.m., the committee was adjourned.]

APPENDIX

Constance Morella 1

Hon. Connie Morella

Opening Statement for Hearing on the Hydrogen Future Act

February 1, 1995

Let me begin by thanking the Chairman for moving forward expeditiously with this worthy piece of legislation. I know that a number of Members share my concern with the impact of fossil fuel consumption on the local and global environment and on human health. Our heavy dependence upon foreign sources of petroleum is also, of course, a matter of high significance to the national security.

The Chairman has spoken wisely in the past about the ability of new technologies to address national and global resource and environmental problems. New environmental technologies—and I would include hydrogen fuel technology in this category—hold the promise not only of environmental improvement but also of opening new worldwide markets for U.S. companies.

The legislation before us would utilize federal research dollars in a very sensible way. No direct subsidies would be offered for industrial product development; however, government dollars will be used to leverage industrial investment in a series of pre-commercial future technologies. I am especially pleased to note that biotechnological

production of hydrogen would be developed and demonstrated under the provisions of this legislation.

I again thank the Chairman, and I look forward to the testimony of our distinguished panel.

*Responses to the Questions
from the Committee on Science
with regards to HR-655--
the Hydrogen Future Act of 1995*

Alan Lloyd, Ph.D.
Chief Scientist
South Coast Air Quality Management District
March 3, 1995
Phone: 909/396-3245

Please note: the enclosed questions were received on February 22, 1995

RESPONSES TO QUESTIONS FROM THE COMMITTEE ON SCIENCE.

Question #1

In your testimony (p.5), you mention that the environmental benefits of hydrogen could lead to a significant reduction in regulations.

Can you provide some specific examples of Federal regulations that could be reduced?

Response #1

Currently, federal and state air quality laws regulate air pollution emissions from a wide spectrum of industries and source types. In many regions, emissions from mobile/transportation sources account for more than 50% of all emissions. These vehicle emissions are generated almost entirely through the combustion and evaporation of hydrocarbon-based fuels. When used in internal combustion engines, hydrogen can yield near-zero emissions, and if used in fuel cells, the result is zero emissions. Therefore, wide-scale introduction of hydrogen as a transportation fuel (especially used in tandem with fuel cells) could virtually eliminate the mobile source emission problem in the United States.[1] Moreover, all stationary source emissions that today result from hydrocarbon combustion to generate electricity could also be eliminated through the use of hydrogen.

This scenario would result in reduced federal regulatory burdens in two important ways. First, since hydrogen and fuel cells would replace hydrocarbon fuels and the internal combustion engine as the predominant means to power everything from vehicles to generators, there would be no need for such sources to be emissions regulated at all. For example, the entire EPA and California programs to test and certify new motor vehicles could be eliminated. Moreover, the general motoring public would not need to be subjected to annual vehicle emissions inspections. In fact, federal regulatory burdens involving a vast number of today's air pollution sources could be reduced significantly, or eliminated entirely. Examples of products and industries that might benefit include:

- construction equipment
- locomotives and other off-road vehicles
- marine vessels and pleasure craft
- cement kilns
- glass furnaces
- brick manufacturing
- electric power plants
- stationary internal combustion engines

(1). Hydrogen can potentially eliminate hydrocarbon emissions from a broad spectrum of mobile sources: light, medium, heavy, and off-road vehicles. Emissions could be eliminated from tailpipe sources, evaporation and from refueling. The last two categories have become even more significant as tailpipe emissions standards are gradually tightened nationwide.

- o gas turbines
- o boilers and heaters

The second way that wide-scale use of hydrogen and fuel cells could reduce regulatory burdens is less direct, but nonetheless very compelling. Simply stated, with vehicle- and combustion-related emissions virtually eliminated, regulatory agencies could ease requirements on all remaining sources of emissions that could not be mitigated through hydrogen use.

A major case in point involves the many miscellaneous stationary sources of volatile organic compounds (VOCs). VOCs combine with nitrogen oxides in the presence of sunlight to form photochemical smog. Currently, a wide variety of industries and consumer products that use paints, coatings, solvents, etc. must rapidly reduce their VOC emissions. Just a few industries that could be given regulatory relief if the use of hydrogen virtually eliminates emissions from vehicles and combustion are as follows: furniture manufacturing, consumer product manufacturing, aerospace manufacturing, automobile painting and assembly, automobile repair, newspaper and magazine printing, coatings and ink manufacturing, and graphic arts.

Question #2

What are the potential cost savings to private industry from such a reduction?

Response #2

Air Quality

Though it is difficult to provide anything but a ballpark number, the cost savings from eased regulations could figure in the tens or even hundreds of billions of dollars **annually** on a nationwide basis.

Recently, the South Coast Air Quality Management District (SCAQMD) adopted the 1994 Air Quality Management Plan (AQMP). This Plan, which is regularly updated every three years, maps out the strategy to meet federal and state air quality laws. When discussing the issue of costs, it is important to first note that there will be tremendous real-dollar benefits from cleaning up the air to meet health-based standards. In fact, a study for the SCAQMD has shown that at least $6.5 billion per year in human-health costs will be saved through restoration of cleaner air in the Los Angeles Basin. Moreover, if you factor in today's real-dollar costs from air pollution in terms of building and agriculture damage, reduced visibility, etc., the price of **not cleaning** our dirty air is even higher.

Now, regarding potential direct cost savings to industry if air pollution regulations could be substantially reduced: according to our 1994 AQMP, the annual costs to industry in this region alone as a result of existing or proposed air quality regulations will be about $5.4 billion. About $4 billion of these costs involve transportation-related sources of emissions. Given that the annual cost of compliance for this region alone is expected to be about five billion dollars, it is fairly safe to estimate that nationwide, the annual cost of compliance for existing clean air laws is at least an order of magnitude higher -- in the tens or hundreds of billions. The vast majority of these savings would accrue to the private sector.

Water Quality

The above refers only to federal clean **air** regulations. Hydrogen could potentially offer substantial water (and soil) quality benefits as well. All over the world, leakage of hydrocarbon-based (i.e., petroleum) fuels are a major source of ground- and surface-water contamination. Annual cleanup costs, including major soil remediation projects, are in the billions of dollars. Disasters like the Exxon Valdez oil spill -- and the associated billion dollar costs that government and private industry incurs for cleaning such spills -- could be avoided. Overall, huge pollution-mitigation costs could be eliminated through wide-scale deployment of hydrogen, which does not pollute water, air, or top soil.

Question #3

What are the potential cost savings to the Federal Government?

Response #3

Costs of Enforcement

We are unable to answer this question precisely because SCAQMD is a regional regulatory agency with experience that is specific only to air pollution control in Southern California. However, we can extrapolate from this experience to make rough estimates for the federal government.

The SCAQMD incurs an annual cost of about $100 million to implement its regulatory activities. These activities include permitting, enforcement, regulation development, laboratory testing, air monitoring, etc. The bulk of the activities focus on industrial stationary sources of air pollution. (The California Air Resources Board, or CARB, incurs similar annual costs to implement its regulatory program, which focuses on mobile source air pollution control.)

As previously noted, wide-scale deployment of a hydrogen energy system would virtually eliminate emissions of combustion-related hydrocarbons, oxides of nitrogen and particulate matter. Consequently, the burden to government agencies of enforcing regulations on industry could be drastically lowered, without sacrificing cleaner air.

It is difficult to precisely estimate such savings. Without undertaking detailed calculations (which are outside the timeframe provided for response to the question) it is only possible to roughly estimate an answer. Based on extrapolations from our own budget for regulatory activities, and after considering what types of regulations could be eliminated through wide-scale use of hydrogen technologies, we estimate that the federal government could save hundreds of millions of dollars per year.

It should be noted that not only the federal government -- but state, regional and local governments throughout the country as well -- could reduce their compliance enforcement burden. The cumulative annual savings could be on the order of $500 million nationwide.

Fuel Efficiency

The other advantage to the federal government is that the hydrogen economy -- especially in tandem with widescale use of fuel cells -- would result in substantial improvements in fuel efficiency. Efficiencies of fuel cell and hybrid hydrogen engines are two to three times greater than current internal combustion engines. Savings in fuel could result in substantial lowering of trade deficits, which is currently weighted down among other factors by huge oil imports. Such trade deficits constrain the flexibility of the federal government to carry out its fiscal and monetary policies. It also increases private and federal indebtedness as private entities and the federal government have to borrow to pay off foreign creditors. (Interest on federal indebtness continues to be among one of the largest contributors to the equally huge federal budget deficit.) A hydrogen economy could make a major dent on oil imports, and hence on private and federal borrowing requirements.

Question #4

What industries, states, or other entities are in the forefront of hydrogen research and development?

Response #4

Resource Allocation

Relative to the substantial benefits hydrogen could potentially provide to the economy, the amount of research and development being conducted on this fuel is currently negligible. Research in alternative fuels in general, and that of hydrogen in particular, is several magnitudes of order less than the research in conventional fuels.

Moreover, tens of thousands of scientists and engineers are working on petroleum fuels and internal combustion engines, which have a relatively limited long-term future, while only a handful are working on hydrogen and fuel cell technologies. This is very short-sighted thinking -- hydrogen is effectively an inexhaustible, 100% sustainable fuel, and most experts agree fuel cells offer tremendous promise to become the preferred powerplant of the next century.

Hydrogen Activities

Within the limited scope of hydrogen R&D efforts, some activities do stand out, and certain states are clearly on the forefront. Today, hydrogen is primarily consumed for space and industrial applications including petroleum refining and the chemical industries. Vendors of hydrogen such as Praxair and Air Products carry a limited amount of research, with modest programs to expand into new markets. Some limited scientific research on hydrogen generation and use is being carried out at universities in California, Florida, and Hawaii.

There is slightly more activity in the fuel cell area. Several manufacturers are developing proton exchange membrane (PEM) fuel cells. (PEM technology is showing great promise and is an ideal application for hydrogen.) Manufacturers include but are not limited to Ballard Power Systems, International Fuel Cells, H-Power Corp., Allied-Signal, Energy Partners Corp., and Humboldt State University.

Lawrence Livermore Lab is developing a hydrogen application for hybrids: a steady-state hydrogen engine that can run at greater than 45% efficiency in tandem with electrical storage devices such as batteries and flywheels. Firms such as Hydrogen Consultants, Inc. in Denver are working on Hythane applications (Hythane is a clean-burning mixture of 7% hydrogen and 93% natural gas that may help to phase in greater use of hydrogen).

Overall, California leads the way in hydrogen development and demonstration activity. At the SCAQMD, we have initiated or joined several key hydrogen and fuel cell projects. Examples include two independent fuel cell transit bus programs, studies on residential electricity generation, and solar-hydrogen generation with zero emissions at the University of California, Riverside. The Xerox-Clean Air Now project within this Basin plans to demonstrate the integration of hydrogen production, storage, and refueling.

Question #5

In your opinion, are these activities focused on the most urgent issues or would you recommend activities that need to be addressed but are not at the current time?

Response #5

Currently, hydrogen projects are generally being conducted on an ad hoc basis. A systematic effort to link these projects is needed. As pointed out in my testimony, there is a compelling need to develop hydrogen corridors -- a concept similar though not identical to the sustainable energy centers proposed by Senator Tom Harkin.

For example, a hydrogen corridor in Southern California could potentially link locations with various hydrogen and PEM fuel cell activities. Various hydrogen technologies -- in the realm of production, distribution, storage, refueling, and end-use -- could be demonstrated and linked together. This attempt to create an integrated infrastructure could help educate the public, the scientific community and policy-makers on the substantial benefits of hydrogen.

As indicated in my testimony, the success of developing a hydrogen economy will be intimately linked with the development of a fueling infrastructure. The importance of infrastructure development cannot be over emphasized. Efforts are underway by DOE and HTAP to give this the necessary attention and resources.

It should be also noted that as a focus area, on-vehicle hydrogen storage is the most important remaining technological challenge. Substantial progress has been made in production, bulk storage, refueling, dispensing and end-use. Once the impediment of storage technology has been overcome, hydrogen vehicles can become more practical, and economy-of-scales use of hydrogen can be achieved.

Question #6

In your opinion, what is the government's role in the development of hydrogen as an energy carrier?

Response #6

The government can be a catalyst to encourage widespread public-private participation in developing hydrogen as a mainstream fuel and energy carrier. Currently, knowledge of hydrogen as a potential beneficial fuel is very limited, even within the scientific and academic communities. Consequently, hydrogen is sometimes thought to be an unsafe fuel, when overall it is in fact as safe or safer than conventional fuels like gasoline. Government agencies can greatly assist in enhancing corporate and public awareness of hydrogen as a safe and environmentally benign fuel.

Besides encouraging basic scientific research, the government can encourage joint public-private partnerships on demonstration projects, which offer numerous benefits, including but not limited to:

- Evaluation of the technical performance and durability of recent technological improvements;
- Education of the public about the latest developments in hydrogen technologies;
- Increase of public, private, and policy-maker support for the fuel.

Given that hydrogen can be a sustainable, environmentally benign fuel, and it offers the potential to provide billions of dollars in cost savings to private industry, the federal government should scale up research and development activities to match those involving current fossil fuels. Without such sizable funding budgets, hydrogen will continue to limp along, at massive expense to humanity in terms of adverse health effects, poor quality of life, and environmental degradation.

As stated in my testimony, government agencies must work with industry to ensure that these technologies are ultimately industry driven, which is essential to their successful commercialization.

energy partners

February 23, 1995

The Honorable Robert S. Walker
U.S. House of Representatives
2369 Rayburn House Office Building
Washington, DC 20515

Dear Congressman Walker,

I am responding to your letter of February 9, 1995, regarding The Hydrogen Future Act of 1995. Listed below you will find a brief summary for each of the questions asked.

- Hydrogen technology is already available in space programs. Logical continuation would therefore be in air transportation. However, the most powerful driving force for hydrogen fuel introduction is the environmental concern, particularly in urban areas, where automobiles as polluters get a lot of attention, but this is a mass-market with very competitive prices. It may be that more emphasis should be placed on introducing hydrogen technology in other areas where its high initial cost would not be such a big impediment. For example, in the case of fuel cells, the low heat signature and quiet operation would indicate its usefulness to the military.

- R&D breakthroughs cannot be planned - they happen. We can however make a wish list:

- practical and efficient method of splitting water directly by solar energy (photoelectrochemistry)

- practical and safe ways of "packing" large amounts of hydrogen in small enclosures

- compact, high power, air breathing fuel cells (new membrane materials, new catalysts).

- Department of Energy and industry should work together. Industry should have more impact on giving directions for R&D (i.e., what is needed by industry and not necessarily what is being proposed by academia), and also on evaluation of R&D progress. Industrial participation in demonstration projects is essential.

I appreciate this additional opportunity to respond to the needs of our industry. Energy Partners will continue to make available to you any resources we can provide to reach our mutual goal, a hydrogen economy.

Sincerely,

Ed Trlica
President

1501 Northpoint Parkway • Technology Center • Suite 102 • West Palm Beach, Florida 33407
Phone (407) 688-0500 • Fax (407) 688-9610

Responses by Robert H. Williams
to
Questions for the Record of the Hearing on the Hydrogen Future Act of 1995
1 February 1995

1. *In your testimony (p. 4), you suggest that "thermochemical gasification of biomass" should be added to the list of production technologies slated for demonstration. Would you please elaborate on the basic technology involved.*

In thermochemical gasification, biomass, which might be in the form of wood chips (e.g. produced from trees grown on dedicated "energy" farms), is reacted with steam and/or limited quantities of oxygen, and heated to temperatures of 600 to 1000 °C. The products of the reaction are mainly carbon monoxide (CO) and hydrogen (H_2). Subsequently, the energy contained in the CO can be "shifted" to H_2 by reacting the CO with steam, in the so-called water-gas-shift reaction (*see Box A*). The gaseous mixture exiting the shift reactors consists mainly of H_2 and carbon dioxide (CO_2). The final step in the H_2 production process is to separate the H_2 from the H_2/CO_2 mixture. Over 90% of the H_2 in this mixture can be separated out at up to 99.999% purity by using pressure swing adsorption technology (*see Box A*). The energy content of the separated H_2 would be over 60% of the energy content of the biomass from which it is derived, taking into account all energy inputs to the process.

As I showed in my written testimony, H_2 can be produced via thermochemical gasification of biomass at about the same cost as H_2 can be produced via the thermochemical gasification of coal, and at much lower cost than H_2 produced via the electrolysis of water, whether the electricity is provided by nuclear power, wind power, or photovoltaic power when cost goals for photovoltaic technology have been reached (*see Figure 14 in my written testimony*).

Also, the lifecycle CO_2 emissions from the entire system of H_2 production from biomass plus its use in a fuel cell vehicle (measured in grams of CO_2 per mile of driving) would be less than 10% of the life-cycle emissions for a gasoline internal combustion engine vehicle and less than 14% of the lifecycle CO_2 emissions for a system using H_2 produced from coal in a fuel cell vehicle (*see Figure 17 in my written testimony*).

All the components of the system needed for producing H_2 from biomass via thermochemical gasification except the gasifier are commercially available. Biomass gasifiers suitable for use in H_2 production are being developed for other applications in ongoing DOE programs (see answer to question 3, below). The needed technology could be commercially ready by the turn of the century with adequate R&D support.

The largest potential supply of biomass for H_2 production is biomass that can be grown on dedicated energy farms on excess agricultural lands--either as fast-growing trees (e.g. hybrid poplar or willow) or perennial grasses (e.g. switchgrass).[1] Once the technologies involved are established in the market, farmers growing biomass energy crops for high value applications such as H_2 for fuel cell vehicles could earn good incomes without having to rely on the federal subsidies that we now pay farmers for not growing food crops.

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[1] Thermochemical gasification is relatively insensitive to the type of biomass used.

A detailed discussion of the technology for producing hydrogen from biomass is given in Williams et al. (1995).

2. *In your opinion, what is the proper role of the Federal Government in funding research and development?*

Government has important roles to play in supporting research and development to compensate for the propensity of private firms to underinvest in R&D. Despite the powerful evidence that the total economic return on investment in R&D is several times as high as that for other forms of investment (Cohen and Noll, 1994), firms tend to underinvest in R&D because they cannot appropriate the full benefits of R&D investments (a free-rider problem), and because some R&D is needed to find ways to lower costs that are not reflected in market prices (e.g. the costs to society of air pollution).

A high level of R&D activity is especially important for countries such as the US that have high per capita income levels, because these countries cannot sustain healthy long-term economic growth rates unless they remain at the cutting edge of technology.[2] Despite this "fact of life" and the central importance of being able to provide inherently clean energy technologies for the large and rapidly growing global energy markets in the decades ahead,[3] private and public sector support for long-term R&D in the energy sector is collapsing in the US, as described in my written testimony.[4]

To remedy the situation intensified efforts are needed in support for precompetitive research, for

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[2] With today's extensive communications networks, technological information travels fast and is assimilated by diverse groups very quickly. After a new technology is introduced, it will typically not be long before countries with low per capita incomes will be able to produce the technology at lower costs than the country with high per capita incomes that originally introduced it. A country with high per capita incomes can advance economically in such a world only by continually innovating.

[3] Most of the world's incremental energy requirements will come from the developing countries in the decades ahead The environment is going to be a growing concern in the developing world as the energy system expands rapidly. The extent to which US and other industrial country suppliers will play significant roles in this large global market will depend on the extent to which they can offer new technologies that are both competitive and inherently clean (i.e. clean without the need for cumbersome control technologies), because conventional technologies with "band-aid controls" will be provided at lower costs by indigenous suppliers.

[4] Since I presented my testimony, new evidence has become available showing that the R&D crisis in the electric utility sector is even worse than was suggested by the data I presented. At the 31 January 1995 Hearing of the Energy Research, Development, and Demonstration Committee of the California Energy Commission on "Restructuring and the Future of Electricity RD&D," it was pointed out that in 1995 RD&D on advanced generation technologies by California investor-owned utilities is expected to decline 88% from 1993 levels, while overall RD&D will decline 32% compared to 1992 levels, moreover, indications are that contributions to the Electric Power Research Institute (EPRI) from California investor-owned utilities and from municipal utilities will be 50% lower in 1995 than in 1994 (ERC&D Commission, 1995). Although good data are not yet available for states other than California, trends elsewhere can be expected to be similar, since the underlying cause is the same everywhere--the increasing competition arising from the ongoing restructuring of the electric utility industry.

Kurt Yeager, Senior Vice President of EPRI, testified that as a result of the increasingly competitive environment in the electric power industry, there has been a dramatic shift in R&D in the electric utility industry toward activities that can lead to near-term cost reductions, along with sharp reductions in long-term R&D (Yeager, 1994).

development and demonstration of new technologies, and for stimulating the commercialization of successfully demonstrated technologies. In my view the best strategy for the US would be to frame an energy R&D program that gives emphasis in all these categories to energy technologies that are inherently clean and safe, with good prospects for becoming competitive in world markets.

Government should provide direct financial support for precompetitive research, both basic and applied, as it is especially difficult for the private sector to appropriate the benefits of investments in precompetitive research. The greatest overall economic benefits from this activity will arise if the results of this research are made widely available. For this research, the fostering of collaborations among industrial firms (both potential producers and potential users of future technologies), government laboratories, and universities would be an effective way both to minimize duplicated effort and to promote effective transfer of technological knowledge to eventual commercial producers. Collaborations in precompetitive research among competing firms need not be avoided, since this research is limited to expanding the technological base of the industry and should not result in cartelization of the research results. Costs could also be reduced by encouraging international collaborations.

For development and demonstration, direct governmental support is also needed. For these activities, it is desirable to protect the intellectual property rights of the developers; otherwise the prospects are poor that the private sector would be motivated to bring the new technology to market. But in return, government funding should be more conditional than for precompetitive research. To begin with, there should be a high level of cost-sharing with industry. Moreover, financing mechanisms that would eventually "make the government whole" might be considered. For example, government contributions to projects might be made through a revolving fund that is replenished by revenues from the eventual sales of demonstrated technologies that are successfully launched in the marketplace. While not all demonstrations can be expected to lead to commercial products, it is reasonable to expect from a well-managed program that there would be enough successes to generate returns adequate to sustain a revolving fund, because on average the economic return on investment in R&D is several times as high as that for other forms of investment (Cohen and Noll, 1994).

Demonstrations are inherently more costly than basic and applied research. However, there is a wide range of "inherently clean and safe" energy technologies that are small-scale and modular, which therefore can be demonstrated for costs that are a tiny fraction of the costs for demonstrating large-scale conventional fossil and nuclear energy technologies (Williams, 1994). By supporting a diverse mix of such modular technologies the government would avoid the trap of having to try to "pick winners." Whatever the funding mechanism, it is imperative that funding for basic and applied research be protected against "raids" to find financial support for demonstration projects during times of fiscal austerity.

Once a technology is successfully demonstrated, it will not automatically be adopted in the marketplace. This is because initially the cost of equipment will typically be higher than its worth in the market, and (as indicated in footnote 4) competitive pressures in today's energy markets make it extraordinarily difficult to introduce any innovative technologies other than those that lead to reduced costs in the very near term. Government incentives for commercialization are generally needed. As incentives at this level of the development process are potentially the most costly, their scope should be relatively narrowly defined. Most importantly, the incentives should be restricted to technologies that offer good prospects for becoming fully competitive without subsidy as cumulative production increases, via cost-cutting from "learning by doing" and continuing technological improvements.

Secondly, the incentives should be "term-limited" and eventually phased out. "Sunset provisions" for the incentives should be made clear to would-be developers from the start. Various instruments can be used to promote commercialization--including government procurement, tax credits, or regulations such as the Non-Fossil Fuel Obligation (NFFO) in the UK; with the NFFO, the costs are borne not by the federal government and taxpayers but by the electricity ratepayer via a small surcharge on the electricity bill.[5]

Economist William Baumol argues that incentives provided for launching technologies with inherently attractive environmental attributes can generate powerful direct economic benefits for the economy as a whole, in addition to the environmental benefits provided (Baumol, 1995). Specifically, Baumol points out that a country's long-term position in world markets would be improved by nurturing the development of environmentally attractive technologies characterized both by (*i*) large start-up costs (arising, for example, from extreme uncertainty and from the absence of experience in the industrial operations) and (*ii*) good prospects for future cost cutting both from learning-by-doing and from technological improvement. This prospect arises because the benefits of such innovations are inherently relatively retainable (i.e. they cannot be easily appropriated by others). Arthur (1990) has also stressed that getting an early foothold in the market can often lead to market dominance, citing, for example, the early competition between VHS and Beta in the VCR market, where neither technology was obviously superior to the other, but small initial gains in the market by VHS led to squeezing Beta off the market entirely.

Whatever the shape of an energy R&D program, its effectiveness will depend to a large degree on there being a relatively stable long term financial commitment to the process that is shielded from the vagaries of short-term market fluctuations and politics, because of the importance of field experience on the part of those who carry out R&D. A special form of this experience known as "tacit knowledge," the unwritten knowledge about how technologies perform in practice, is key to the success of technological development (Dosi, 1988) and can easily be lost when R&D programs are destabilized.

To sum up, if initiatives are launched to address the unfolding energy R&D crisis with a well-crafted energy R&D program that builds on its historically demonstrated technological strengths, the US would stand a good chance of playing major roles in the global energy markets of the 21st century. But if the present trends in private- and public-sector support for energy R&D persist, the US will instead become a minor player on the world energy scene.

3. What industries, states, or other entities are in the forefront of hydrogen research and development? In your opinion are they focussed on the most urgent issues or would you recommend activities that need to be addressed but are not at the current time?

There is some ongoing research and development relating to the hydrogen production, hydrogen storage, hydrogen use, hydrogen systems, and hydrogen systems analysis--some of which is reviewed

[5] The Non-Fossil-Fuel Obligation (NFFO) is a statutory mandate in the UK that the privately owned-utilities buy specified quantities of electricity from non-fossil fuel plants and pay for the excess costs (if any) via a surcharge on fossil fuel electricity. The NFFO has been powerfully effective in bringing costs down for some of the innovative non-fossil fuel technologies involved. For example, wind farms in the first NFFO buy in 1990 were contracted at 6 pence per kWh, but by 1994 some wind farms were contracted at 3.9 pence per kWh (Elliott, 1994).

here. The DOE can provide an annotated list of DOE contractors. Additional information can be obtained from the National Hydrogen Association, which prepared a report last year that surveyed a large number of hydrogen projects (Mauro and Smith, 1994). Also, Peter Hoffman, editor of *The Hydrogen Letter*, maintains an international hydrogen directory.

Hydrogen production. The leading producers of hydrogen at industrial scale are Air Products, Praxair, and British Oxygen, for hydrogen derived from natural gas and the Electrolyzer Corporation (of Canada) and Teledyne for hydrogen derived electrolytically from water; these companies do some R&D. While they may not have significant hydrogen production programs, Texaco, Shell, and Desetec have developed oxygen-blown coal gasifiers that could be used for producing hydrogen from coal (*see Box A*). Although no biomass technology developer is working on hydrogen production from biomass, two indirectly heated gasifiers being developed with US DOE support for other applications [support to build a Battelle Columbus Laboratory (BCL) gasifier in Vermont that will eventually be used for electric power generation and support for use of the MTCI gasifier by Weyerhauser in North Carolina for black liquor gasification in the pulp and paper industry] are well suited for producing hydrogen from biomass (Williams et al., 1994).

Hydrogen storage. I include under storage, R&D on both direct storage of hydrogen and R&D on converting alternative hydrogen carriers (e.g. hydrocarbon fuels, alcohol fuels, or sponge iron) into hydrogen at or near the point of final use. (In the latter instances the storage function is provided by the hydrogen carrier before it is transformed into hydrogen.) Lawrence Livermore Laboratory, NREL, and Syracuse University are working on innovative approaches for storing hydrogen. Haldor Topsoe, Howe-Baker Engineering, and Hydro-Chem are developing steam reformers for stationary hydrogen production from natural gas. A.D. Little and Hydrogen Burner are developing on-board partial oxidation units for converting hydrocarbon or alcohol fuels into hydrogen for vehicular applications. Allied Signal Corporation, Ballard Power Systems Inc. (of Canada), and International Fuel Cells (IFC) are developing methanol reformers for use in fuel cell vehicles. H-Power is developing technology for using sponge iron as a hydrogen carrier and "steam-oxidizing" it on-board vehicles to produce hydrogen.

Hydrogen use. In North America the leaders in proton exchange membrane (PEM) fuel cell development are Allied Signal Corporation, Ballard Power Systems Inc. (of Canada), H-Power of Belleville, NJ, IFC, and Energy Partners, Inc. IFC is also a major developer of phosphoric acid fuel cells, which will be used mainly for stationary power applications. Both Dupont and Dow have developed membranes for use in PEM fuel cells. Ballard has a joint venture with Dow Chemical to develop PEM fuel cell cogeneration systems for buildings and with Daimler Benz to develop PEM fuel cells for cars.[6] H-Power has demonstrated, under DOE contract, a bus based on the use of methanol (a hydrogen carrier) and its on-board reforming to hydrogen and use in a phosphoric acid fuel cell. Ballard demonstrated a 34-foot hydrogen PEM fuel cell bus in 1993 (supported in part by the SCAQMD) and will demonstrate a 40-foot bus using a more advanced PEM fuel cell later this year.[7]

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[6] Daimler Benz unveiled a hydrogen-powered PEM fuel cell-powered proof-of-concept van in April 1994. Daimler-Benz has invested $60 million so far in fuel cell research for transportation and has plans to produce a production-ready prototype vehicle within 5 years.

[7] Using a fuel cell that will produce 2.6 times as much power as was provided by the fuel cell with the same volume that was used in their 1993 prototype bus.

LANL is doing basic and applied research on PEM fuel cells, and Texas A&M University is doing basic and applied research on PEM and other fuel cells as well. PEM fuel cell systems for vehicles are being developed at LANL and by Allison Gas Turbines. All the Big Three Auto Manufacturers are considering PEM fuel cells based on the use of hydrogen or a hydrogen carrier as candidates for meeting the goals of the Partnership for a New Generation of Vehicles (PNGV) and have programs that are exploring these options. The GM PNGV "team" involves Allison, Ballard, Dow, Dupont, and LANL; the Chrysler/Pentastar team involves the Aerospace, Automotive,and Engineering Divisions of Allied Signal; and the Ford team involves IFC, H-Power, Tecogen, Directed Technologies, Air Products, Airco, Praxair, and Electrolyzer. Also, a fuel cell vehicle laboratory is being established at the University of California at Davis. And Lawrence Livermore Laboratory is conducting research on hydrogen-powered internal combustion engine vehicles.

Demonstrations of hydrogen systems. The following are some demonstration projects underway in the US:

o Clean Air Now, along with its project participants (US DOE, Xerox, SCAQMD, The Electrolyzer Corporation, Praxair, University of California at Riverside, and others) is building a photovoltaic/electrolysis system for providing hydrogen for 3 retrofitted internal combustion engine utility pickup vehicles at the Xerox Corporation facilities at El Segundo, California.

o A Humbolt State University group, in collaboration with the City of Palm Desert, California, and the Lawrence Livermore National Laboratory, are designing, and will build and operate a fleet of personal utility vehicles and neighborhood electric vehicles that will be powered by hydrogen PEM fuel cells, along with two hydrogen refueling stations--one solar powered, the other wind-powered, and a PEM fuel cell service and diagnostic center.

o Energy Partners, Inc., is developing a fleet of five limited-power PEM fuel cell vehicles for commercial testing in a demonstration serving the City of Palm Springs, California, and its Regional Airport.

o A University of California at Riverside group is developing, installing, and evaluating systems for producing electrolytic hydrogen from photovoltaic sources and for refueling hydrogen vehicles, as well as demonstrating a state-of-the-art hydrogen internal combustion engine vehicle.

Hydrogen systems analysis. In addition to the systems analysis being done by various vendors and consultants to them, hydrogen systems analysis is being carried out at the University of California at Davis, the University of Miami, Princeton University's Center for Energy and Environmental Studies, and Directed Technologies, Inc.

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In my opinion, the areas that warrant far more R&D support than they are receiving at present are:

o Low temperature fuel cells suitable for both transport and stationary cogeneration applications (PEM and possibly other low temperature fuel cells) and ancillary areas (including, for vehicular applications, on-board hydrogen storage and on-board partial oxidation or reforming of various hydrogen carriers). Here the current level of R&D activity in the US is far below

what is warranted, in light of the promise of the technologies.

- Production of hydrogen and various hydrogen carriers (e.g. methanol and sponge iron that would be reduced from "rust," the oxidized form of iron) from biomass based on thermochemical gasification. As I have already pointed out, this could well be the least costly way to produce hydrogen from a renewable energy source--yet there is no R&D activity in this area at present.

- Field demonstrations of entire systems for producing, storing, and using hydrogen. A high priority in this area should be demonstration (in the period ~ 1998) of fleets of fuel cell buses, involving extensive field experience with fuel cell buses in routine use. Such demonstrations are important to illustrate to users, potential producers, and the general public, how hydrogen systems would work, how clean they would be, and their safety.[8]

[8] It is noteworthy that the vehicles at Munich Airport will be converted to hydrogen--first hydrogen-fueled internal combustion engine vehicles and later hydrogen fuel cell vehicles.

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Box A: The Role of the Water-Gas-Shift Reaction In Producing Hydrogen from a Carbon-Rich Fuel

It is feasible to convert a carbon-rich fuel into hydrogen at relatively high overall efficiency by taking advantage of the thermodynamics of the so-called water-gas-shift reaction.

Suppose it is desired to make hydrogen (H_2) out of carbon (C). The first step is to gasify C by partial oxidation to produce carbon monoxide (CO):

$$C + 1/2\ O_2 \text{ -----> } CO, \quad \Delta H_R = -\ 110.5 \text{ MJ/mol}.$$

Note that with complete oxidation,

$$C + O_2 \text{ -----> } CO_2, \quad \Delta H_R = -\ 393.5 \text{ MJ/mol},$$

which shows that the CO produced in partial oxidation retains 71.9% of the higher heating value (HHV) of the original C:

$$HHV_{CO} = 283.0 \text{ MJ/mol},$$
$$HHV_{C} = 393.5 \text{ MJ/mol}.$$

The HHV of H_2 is approximately the same as the HHV of CO:

$$HHV_{H2} = 285.8 \text{ MJ/mol}.$$

The next step is to use the water-gas-shift reaction:

$$CO + H_2O_{(g)} \text{ ------> } CO_2 + H_2, \quad \Delta H_R = -\ 41.2 \text{ MJ/mol},$$

a slightly exothermic reaction that makes it possible to "shift" the energy contained in the CO to H_2. The needed steam (gaseous water, $H_2O_{(g)}$) can be raised by evaporating liquid water ($H_2O_{(l)}$), a phase change (PC) that requires just slightly more heat than is generated in the water-gas-shift reaction:

$$H_2O_{(l)} \text{ ------> } H_2O_{(g)}, \quad \Delta H_{PC} = +\ 44.0 \text{ MJ/mol}$$

Note that the extra heat required (44.0 - 41.2 = 2.8 MJ/mol) can be met using just 2.5% of the heat released via the initial partial oxidation of C. In theory, it is possible therefore to generate 1 mole of H_2 from 1 mole of C at an overall efficiency n = 100*(285.8/393.5) = 72.6%.

The final step in the production of H_2 from C involves separating out the H_2 from the gaseous H_2/CO_2 mixture--for example, using commercial pressure swing adsorption (PSA) technology that can recover 90% or more of the produced H_2 at up to 99.999% purity. (PSA exploits the ability of porous materials to selectively adsorb specific molecules at high pressure and desorb them at low pressure; the cyclic pressure *swing* is what gives the process its name.)

In the real world, H_2 fuel would be made from natural gas, coal, or biomass. H_2 can be produced from natural gas at an overall real-world efficiency of 84% via a process that begins by reacting natural gas with steam (Williams, et al., 1994). This is much higher than the above efficiency because natural gas (mainly methane, CH_4) already contains a great deal of H_2. The real-world efficiencies for making H_2 from coal (whose chemical composition can be represented as ~ $CH_{0.8}O_{0.08}$) via oxygen-blown gasification and from biomass (whose chemical composition can be represented as ~ $CH_{1.5}O_{0.7}$) via steam oxidation are each about 64% (Williams et al., 1994).

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